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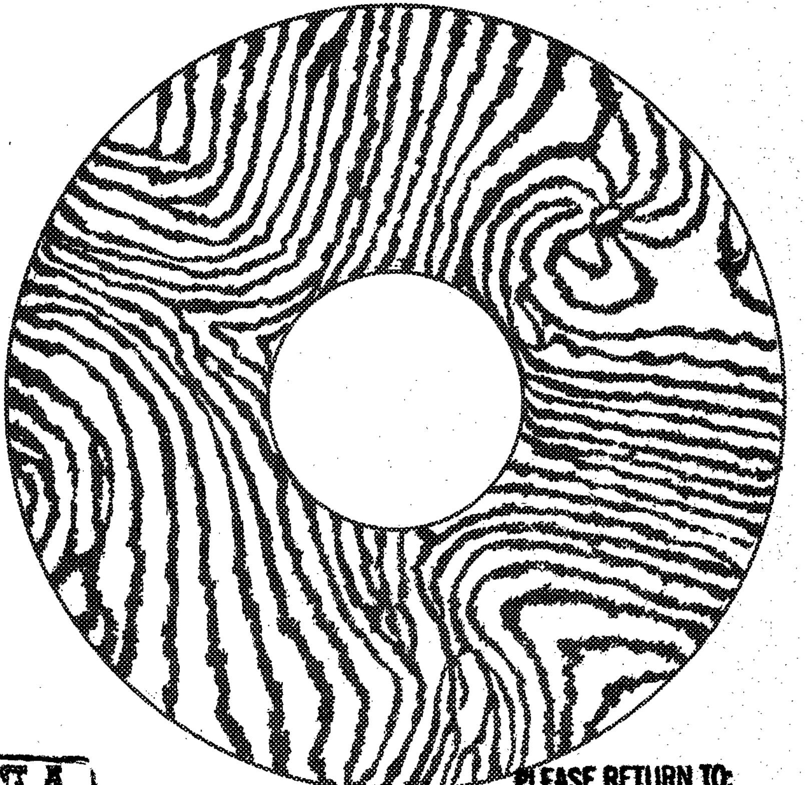

DIGITAL CONTROL SYSTEM DEVELOPMENT FOR OPTICAL MIRROR FIGURE CONTROL

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December, 1971

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DIGITAL CONTROL SYSTEM DEVELOPMENT FOR OPTICAL MIRROR FIGURE CONTROL

ABSTRACT

The maintenance of accurate primary mirror figure in the face of environmental disturbances is the key to the achievement of diffraction-limited performance in a large space telescope. In order to develop the concepts of optical mirror figure control, an experimental program has been initiated at the Marshall Space Flight Center, Huntsville, Alabama. A major component in this experiment will be an XDS Sigma 5-2 multi-digital computer system which will realize the mirror figure control algorithm.

Development of the control system for the experimental active mirror was initially described in two earlier MIT/DL reports in this series.[1, 2] This report extends the previous work in several areas. Figure control laws, suitable for digital computer implementation, have been designed and incorporated in a very flexible software package. A figure control system simulation capability was achieved by including models of the figure sensor, figure actuators, mirror structure and a simulation control module in the software package. This permits the figure sensor control software to be completely checked out and evaluated using the simulation before interface with the actual hardware components is attempted.

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CHAPTER 1

AN EXPERIMENTAL ACTIVE MIRROR

1.1 Introduction

Astronomical observations through a large earth-based telescope suffer from limitations placed on the resolving power of the telescope by fluctuations in the earth's atmosphere. As part of a space orbiting astronomical laboratory, however, a telescope would not be subject to these limitations. A large instrument which is diffraction-limited over a major part of its useful spectrum of observation is envisioned. Maximum resolving power requires extremely accurate maintenance of the figure of the primary mirror.[1-9]

Although it is possible to polish a large mirror to the desired surface accuracy, stresses introduced by thermal variations in the mirror and fluctuations in support structure loads, structural instability and the elimination of gravity loading in orbit could create surface perturbations which would exceed the surface accuracy limits required for diffraction limited performance. As a result, investigators have attempted to develop techniques for actively correcting the mirror figure in a space environment and a number of promising control techniques have been developed.[1-9] The development and application of these control concepts is one of the key challenges facing the designer of the large space telescope.

The development of Mirror Figure Control Systems at the M. I. T. Draper Laboratory was initially on a theoretical level which defined hypothetical analytical models of the various figure control system components and the control algorithms necessary to achieve figure control.[1] An investigation was also made of the potential improvement in rms deformable mirror figure accuracy as a function of the number of actuators used and their arrangement. These studies indicated the basic feasibility of figure control and the fact that substantial improvements in figure accuracy could be achieved even with a relatively modest figure control system realization. While the large scale digital computer is an extremely valuable tool for the analysis and simulation of complicated mirror figure control systems, the results obtained are only as reliable as the modelling accuracy of the physical components in the system. Accurate modelling requires a considerable amount of intuition if the trade-off between modelling accuracy and computation time and analytical difficulty are to be resolved satisfactorily. Often, terms neglected in the modelling process are of key importance to the overall system design.

To resolve these problems it is important to have some way of checking the results of numerical analysis against actual system behavior. Such checks are furnished by an experimental program.

Experimental work in the past has been largely conducted using analog devices to synthesize figure actuator commands from surface error measurements. As a result of the expense and time associated with programming a general purpose analog computer or constructing a special purpose analog system, it has been difficult to explore the full spectrum of control solutions or efficiently process experimental data.

In response to these problems, a more efficient experimental tool has evolved in the hybrid digital analog computer system. Spurred by declining cost hybrid computing systems are appearing in a wide variety of laboratory environments. Software has been developed at MIT/DL which permits a hybrid digital computer to provide the sensor signal processing and control computations for an experimental active mirror figure control system.

1.2 Experiment Design Concept

The experimental system consists of the primary mirror fitted with actuators for figure modification, a mirror figure sensor and an "on line" control system processing the figure errors measured by the sensor to provide proper corrective signals to the actuators.

Following a modern approach a digital computer has been selected as the control processor of the experimental system. The utilization of a general purpose computer has a number of advantages, including:

1. Programmability permitting a large number of different primary mirror control configurations to be investigated without extensive hardware modification.
2. The ability to handle a number of auxiliary tasks such as experimental data processing and display.
3. Characteristics similar to the system computer which will be used in an orbiting astronomical observatory.

A simplified block diagram of an experimental active mirror is shown in Figure 1.2.1. The digital computer consists of a central processor, a random access core memory and an input-output processor. The central processor handles arithmetic operations, logic operations and some data transfer operations using instructions extracted from the core memory. The input-output processor controls the transfer of information from the central processor and core memory to computer peripherals which are part of the interface with the real world. The core memory holds two types of stored information, program instructions and program storage. The program instructions tell the computer what to do with information extracted from program

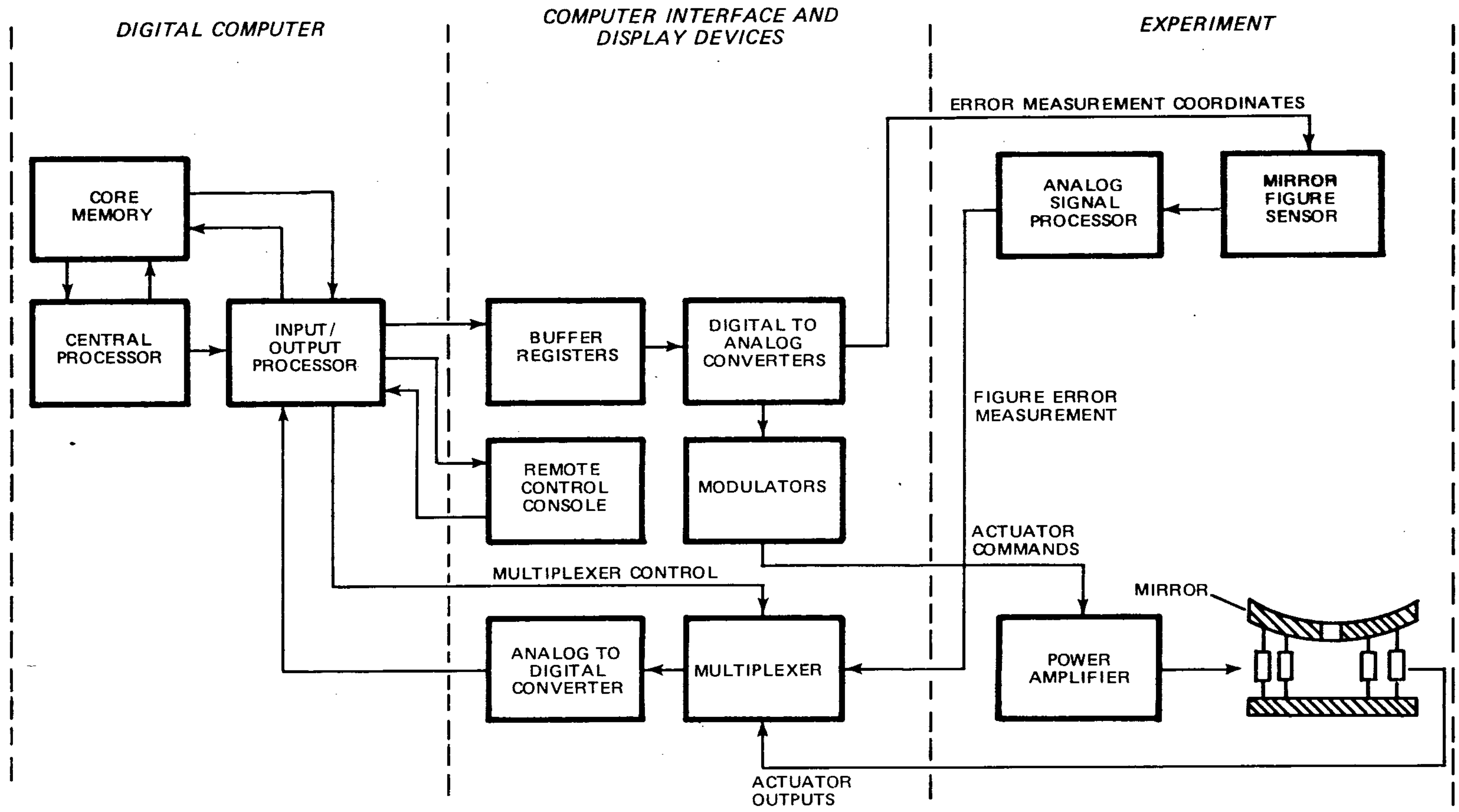


Fig. 1.2.1 A digital control system for an experimental active mirror.

storage and input devices.

The interface consists of a number of components. The *digital output buffers* are a set of addressable registers which temporarily store digital information, which is converted to an analog signal by the digital to analog converters. The output signals from the *digital to analog converters* provide measurement coordinate signals for the figure sensor image dissector and actuator command signals which are modulated by DC-AC *modulators.* The modulator outputs are amplified by the actuator *power amplifiers* to provide sufficient energy to drive the actuator motors. The state of the hardware is observed by the computer via means of the actuator output sensor and the figure sensor error measurements. The analog figure sensor and actuator output signals pass through a computer-controlled switch or *multiplexer*; the single output of the multiplexer is converted to a digital signal by the *analog to digital converter.* The digital signal is then transferred to the central processor or the correct location in the core memory by the input-output processor.

1.3 Software Design Considerations

The actual experimental system is complicated by the use of two computers rather than one as indicated in Fig. 1.2.1. The real time control computations are performed in an XDS Sigma 2 computer which is available to the experiment on a dedicated basis. The relatively small memory capacity of this computer severely limits the scope of the program which it can successfully execute. As a result, it was decided to use a second, more powerful, computer, the XDS Sigma 5 to perform most of the complex arithmetic and data processing operations on a time-shared basis. This decision necessitated the development of an elaborate software module to transfer program control and data from the 5 to the 2 and vice versa.

A digital simulation capability was also realized to provide numerical data for comparison with experimental results and to aid in the development of figure control strategies. The real time control software for the EAM is an integral part of the simulation which in essence substitutes mathematical models for the actual hardware components.* Selection of the simulation mode, hardware control mode, and various other operating configurations is accomplished via a set of mode selection variables.

* Using the techniques successfully employed during the Apollo program.

CHAPTER 2
EXPERIMENTAL ACTIVE MIRROR COMPONENT MODELS

2.1 Introduction

The hardware components of the experimental active mirror consist of devices to measure the figure error, figure sensors, figure actuators for effecting changes in the mirror figure and the primary mirror structure itself.

In order to analyze and to simulate the experimental active mirror it is necessary to develop mathematical models of the system hardware components. This chapter describes the major EAM components and presents simplified mathematical models which characterize their operation.

2.2 Optical Figure Sensor

The figure error measurement function is provided by the optical Figure Sensor.[8, 10] The Figure Sensor is a modified Twyman-Green two-beam interferometer. The interferometer utilizes a laser to produce a coherent beam of light. The plane laser wavefront enters a beamsplitter where it is divided into two beams. One, a reference beam, is allowed to illuminate a plane reference mirror, the second beam is passed through an aspheric decollimating lens which creates a spherical wavefront illuminating the unobscured aperture of the mirror under test. In the case of a spherical primary mirror, coincidence is maintained between the centers of curvature of the primary mirror figure and the spherical wavefront emanating from the decollimator. The reflected energy from the primary returns through the decollimator where collimation occurs. The collimated wavefront mixes with the reflected energy from the reference flat mirror at the beamsplitter producing an interference pattern which is imaged on the face of an image dissector tube.

Irregularities in the spherical primary mirror figure result in a nonspherical returning wavefront and ensuing fringes in the interference pattern. Since a one to one relationship exists between position in the interference pattern and position on the mirror surface it is possible to identify the location of figure errors.

The actual measurement of the magnitude of the figure error is accomplished electronically. Suppose that the reference mirror is mounted on a piezoelectric crystal arranged so that the introduction of an electric field produces an axial translation of the mirror varying the optical path difference between the two arms of the interferometer. The variation in path produces a sinusoidally related change in the interference pattern intensity. The current system utilizes a triangular driving signal to modify the path length which results in a number of cycles variation in the intensity level. As a result, interference pattern information provided by the image dissector is of a sinusoidal nature. The frequency associated with the intensity variation is the product of the optical path difference modulator drive frequency times the number of complete cycles of intensity variation during each complete path length modulation cycle. The sinusoidal variation in the interference pattern at a designated point, sampled by a photodiode, is used to provide a reference signal. The phase difference between the intensity variation at the reference point and a measurement point in the interferogram, observed by the image dissector, is proportional to the figure error at the measurement location. Measurement ambiguity arises from the inability of the phase detector to differentiate phase shifts which are multiples of 360 degrees.

The output of the figure sensor contains noise which arises from mechanical vibrations and internal sources within the optical and electronic components. The noise appears to be adequately modelled by a white noise superimposed on the phase detector input.

The most important characteristics of the Figure Sensor are summarized in Table 2.2.1.

TABLE 2.2.1

FIGURE SENSOR PARAMETERS

PARAMETER	VALUE
OPERATING WAVELENGTH	632.8 nm
PHASE DETECTOR CARRIER FREQUENCY	180 hz
PATH DIFFERENCE MODULATOR FREQUENCY	18 hz
PATH DIFFERENCE MODULATION AMPLITUDE	3164 nm
PHASE DETECTOR FILTER TIME CONSTANT	0.159 sec
ABSOLUTE FIGURE SENSOR ACCURACY	6.32 nm* (after calibration)
FIGURE SENSOR NOISE LEVEL	3.16 nm* rms

*Perkin Elmer performance goals

2.3 Optical Figure Sensor Model

A model of the Figure Sensor has been developed which provides a reasonably good approximation to the actual characteristics of the Figure Sensor. A block diagram of the Figure Sensor model is illustrated in Fig. 2.3.1. The model consists of a Gaussian white noise generator which superimposes noise on the actual figure error β_{xf}, a phase detector model which produces an output β_p equivalent to that provided by the Figure Sensor phase detector and a first-order filter which smooths the phase detector output.

Let the actual figure error at the measurement point coordinates be designated β_{xf}. If the noise superimposed on the figure error is β_{nf}, a suitable form for the phase angle generator is

$$\beta_p = \left[\begin{array}{lll} \beta_{xa}, & |\beta_{xa}| < & \frac{\lambda}{4} \\ \beta_{xa} - \frac{\lambda}{2}, & \beta_{xa} \geqq & \frac{\lambda}{4} \\ \beta_{xa} + \frac{\lambda}{2}, & \beta_{xa} \leqq & -\frac{\lambda}{4} \end{array}\right. \qquad (2.3.1)$$

where

$$\beta_{xa} = \beta_{xf} + \beta_{nf} \qquad (2.3.2)$$

and β_p is the phase detector output. Note that this representation will only provide a useful phase output for figure errors in the range

$$|\beta_{xf}| < \frac{3\lambda}{4} \qquad (2.3.3)$$

This restriction was introduced to simplify model computations while still permitting sufficient range to investigate the measurement ambiguity problems which arise at figure errors of $\frac{\lambda}{4}(1 + 2i)$ where i is an integer.

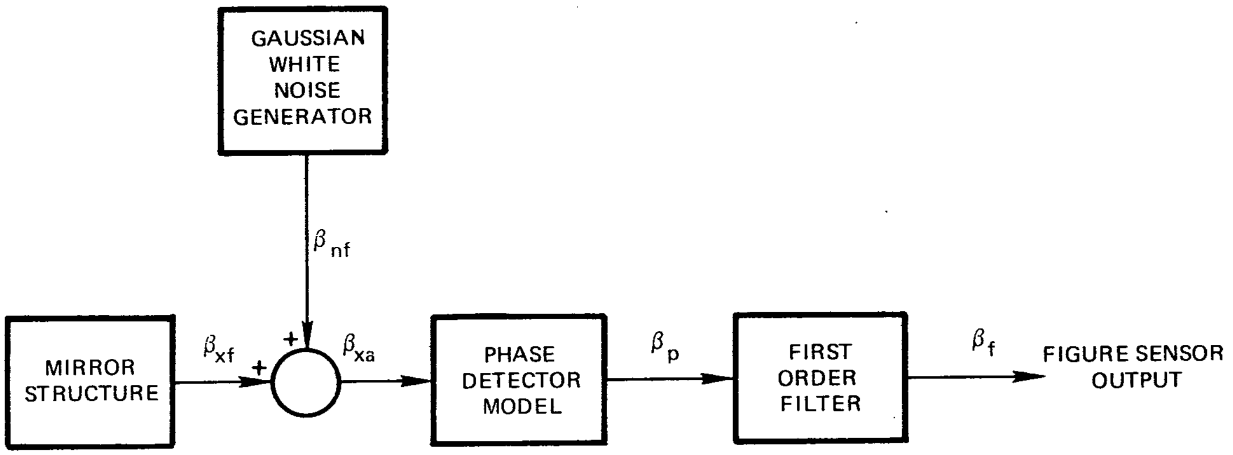


Fig. 2.3.1 Figure sensor model.

The noise input β_{nf} is a Gaussian white noise with zero mean and a standard deviation σ_f.

The figure sensor phase angle filter is modelled by a first-order time lag. A discrete representation of the filter was utilized to save computer time and improve accuracy. The filter has the form

$$\beta_f(i+1) = \varphi_f \beta_f(i) + \gamma_f \beta_p(i) \qquad (2.3.4)$$

$$\beta_f(1) = 0 \qquad (2.3.5)$$

where $\beta_f(k)$ and $\beta_p(k)$ are the filter input and output at time t_k and

$$t_{k+1} = t_k + \Delta t \qquad (2.3.6)$$

where Δt is the real time control loop cycle time. The state and input transition parameters φ_f and γ_f are given by

$$\varphi_f = e^{-\frac{\Delta t}{t_f}} \qquad (2.3.7)$$

$$\gamma_f = 1 - \varphi_f \qquad (2.3.8)$$

where t_f is the time constant of the first-order lag.

2.4 Ambiguity Sensor

Axial alignment of the individual segments to assure that the resultant figure lies on the surface of a sphere centered on the figure sensor decollimator requires measurement of the relative position of adjacent segment edges. While the Figure Sensor can provide accurate figure measurements over a continuous surface it is unable to resolve multiple half-wavelength ambiguities at the discontinuity presented by the divisions between adjacent segments. To eliminate this problem an additional sensing device has been added to the segmented mirror system.

The ambiguity sensor is a modification of the Michaelson interferometer spectrometer in which the interferogram produced by varying the relative length of a two-beam interferometer may be analyzed to determine the spectral content of the excitation source.[13] In the case of the segmented mirror the interferometer is mounted across the adjacent segment edges as indicated in Fig. 2.11.1. Light provided by a tungsten arc source is allowed to impinge on the adjacent segment reflecting surfaces. A Koester prism performs the functions of beam-splitting and recombination. The broad spectrum of the source results in a zero-order interference lobe which is readily recognizable by a peak in intensity. Signal processing is simplified by modulating the arc source with a mechanical chopper permitting the use of ac signal processing techniques. Two lead sulphide detectors are used to examine the interference pattern: one providing a reference signal while the other observes the interference pattern. The difference between the detector outputs is a measure of the intensity of the interference lobe.

2.5 Ambiguity Sensor Model

Assume that an array of measurement points x_f have been defined on the surface of the segmented mirror. Suppose that six of the points coincide with or are near the areas observed by the white light interferometers. The six point elements of x_f are conveniently identified by the elements of a 2×3 array L_f. Thus ambiguity sensor 1 observes measurement points ℓ_{11} and ℓ_{12} and so forth.

A suitable model for the ith ambiguity sensor may be obtained by expanding the ambiguity sensor output as a function of the difference between the ℓ_{i1} and ℓ_{i2} elements of x_f in a Taylor's series. Let the ith ambiguity sensor output be a_{si}. Then

TABLE 2.5.1

AMBIGUITY SENSOR MODEL PARAMETERS

β_{sm}	1.0
β_{sd}	$-\frac{4.0}{\lambda^2}$

$$a_{si} = \beta_{sm} + \beta_{sd} \left[(x_f)_{\ell i,1} - (x_f)_{\ell i,2} \right]^2 \qquad (2.5.1)$$

where β_{sm} is the maximum output of the sensor and β_{sd} is a negative parameter. Note that this model is only capable of adequately representing the zero order node which has a width of approximately ± 316 nm ($\lambda/2$ at 632.4 nm). This is a reasonable restriction since errors in excess of 316 nm would result in axial alignment to the peak of the second node. Note that this implies that initial manual axial alignment must be performed to at least an accuracy of 316 nm. The values selected for β_{sm} and a_{si} are summarized in Table 2.5.1.

2.6 Mirror Figure Actuators

Modification of the primary mirror figure is induced by mechanically perturbing the surface of the mirror. In the case of the deformable mirror figure, modification is produced by an array of controllable loads which elastically deform the mirror structure. The loads act virtually parallel to the optical axis. The segmented active mirror, on the other hand, utilizes mechanical displacement of the individual segments to improve the overall mirror figure.

2.7 Force Actuators

A functional block diagram of the force actuator is shown in Fig. 2.7.1. The actuator servo accepts an angular velocity command from the actuator digital to analog converter channel. The commanded velocity modulates a 400-Hz signal to produce a velocity signal ω_c^*. The transfer function relating the rms modulator output to the dc input signal is assumed to be a constant k_{mod}. The output of the modulator is compared with a corresponding 400-Hz signal ω_a^* which is proportional in amplitude to the angular velocity ω_a of the servo-motor shaft output shaft. The servo motor produces a torque which is proportional to k_t

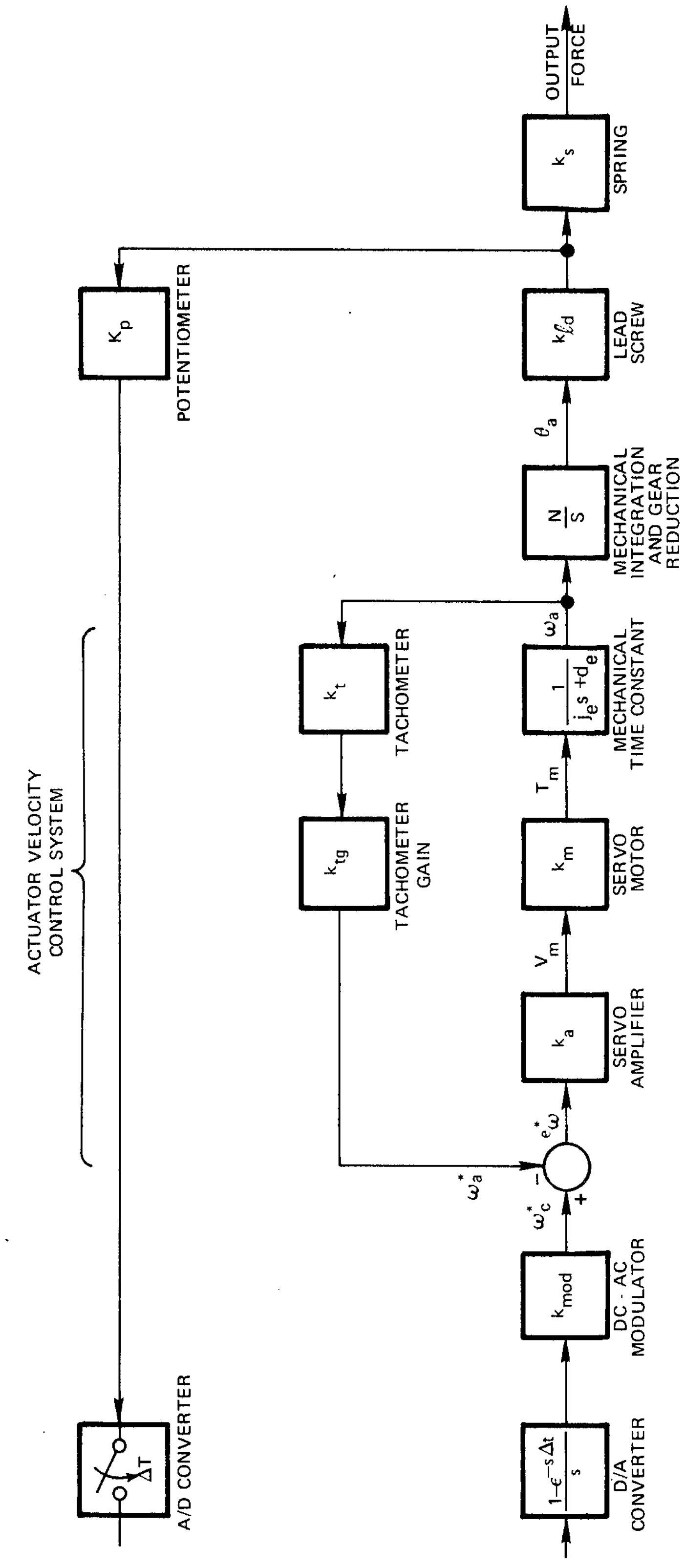


Fig. 2.7.1 Force actuator block diagram.

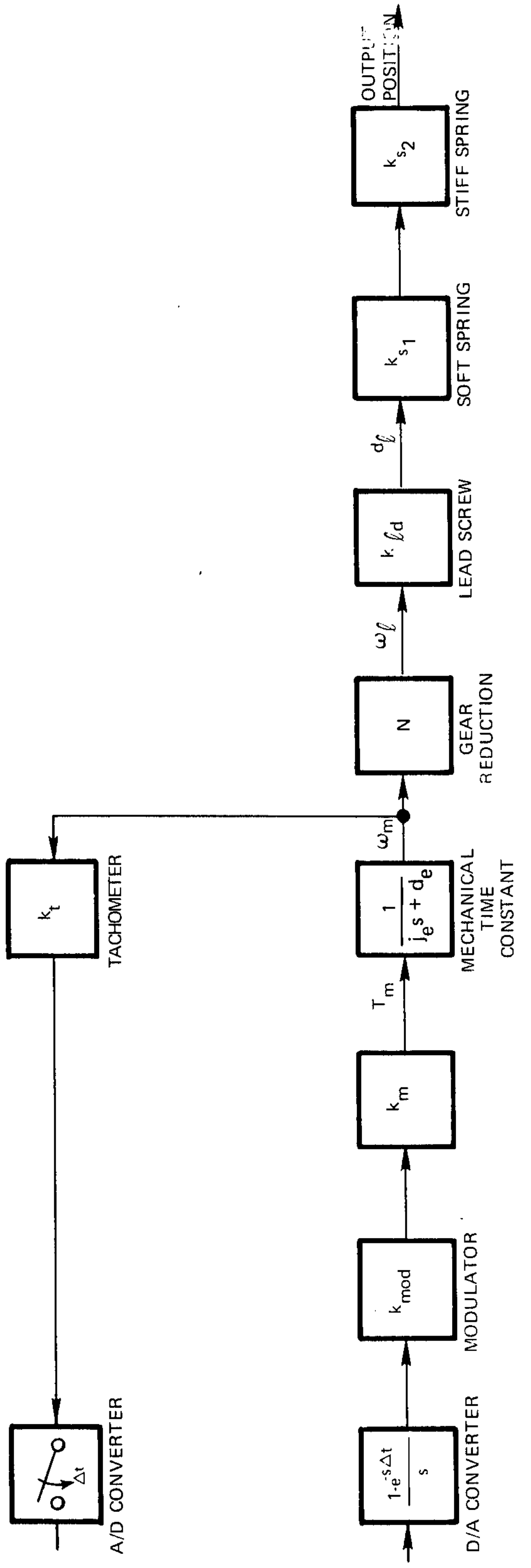


Fig. 2.8.1 Position actuator block diagram.

times the amplitude of the error signal e_ω^*. The direction of the torque T_m depends upon whether or not e_ω^* is in-or-out-of-phase with a 400-Hz reference signal. The torque accelerates the equivalent motor armature and load inertia j_e subject to the damping torque $d_e\omega$. The angular rotation of the motor shaft produces a reduced rotation at the output of a gear reduction. Conversion to linear motion is achieved using a lead screw. The linear movement of the threaded collar on the screw compresses a spring which provides the desired actuator output force. A linear potentiometer slider is connected to the collar to provide a position feedback signal which is proportional to the actuator output force.

2.8 Position Actuators

The position actuators are in some respects similar in design to the force actuators. A motor-tachometer drives a lead screw through a gear reduction. A threaded collar converts the rotation of the screw to linear motion compressing a soft spring. The change in load produced by the fine spring alters the length of a very stiff spring. The change in length of the stiff spring produces a corresponding displacement in the mirror segment through a kinematic support point. The main difference stems from the absence of an actuator output position feedback sensor, a change which alters the character of the control command required to drive the actuators. Actuator position control is achieved by commanding an output velocity pulse whose total area equals that of the desired change in position. The commanded velocity drives a velocity control loop which is closed in the Sigma 2. A block of the segment position actuator is shown in Fig. 2.8.1.

2.9 Actuator Models

The actuator control systems are characterized by a fast inner loop which controls the angular velocity of the tachometer-motor and a relatively slow outer loop which controls the position of the threaded lead screw collar. As a result it was decided to model the transfer function between the desired, m_c, and actual, m_m, actuator outputs by a simple first-order system. For the ith actuator

$$\dot{m}_{mi} = \frac{1}{t_{ai}} \left[m_{ci} - m_{mi} \right] \qquad (2.9.1)$$

The time constants t_{ai} i = 1, n_r are read in as elements of the array TACTV. In order to eliminate the need for numerical integration the actuator dynamics were represented by the equivalent discrete equation

$$m_{mi}(i+1) = \varphi_{ai} m_{mi}(i) + \gamma_{ai} m_{ci}(i) \qquad (2.9.2)$$

where $m_{mi}(k)$ and $m_{ci}(k)$ are the values of m_{mi} and m_{ci} at t_k and

$$t_{k+1} = t_k + \Delta t \qquad (2.9.3)$$

where Δt is the actuator control system cycle time. The state and input transition parameters φ_{ai} and γ_{ai} satisfy the equations

$$\varphi_{ai} = e^{-\frac{\Delta t}{t_{ai}}} \qquad (2.9.4)$$

$$\gamma_{ai} = 1 - \varphi_{ai} \qquad (2.9.5)$$

where t_{ai} is the time constant associated with the ith actuator.

2.10 Deformable Mirror Model

2.10.1 Introduction

A linear model of the deformable mirror is desired which relates the displacements x_f sensed by the figure sensor at an array of measurement points to the loads m_m applied parallel to the optical axis by an array of force actuators. The linear transformation is conveniently expressed in the form

$$x_f = A\ m_m \tag{2.10.1}$$

where A is an n × n matrix.

A linear model of the form (2.10.1) is conveniently generated by representing the mirror by an approximate structural model consisting of a large number of finite elements as indicated in Fig. 2.10.1. The node points (joints) of the finite element representation are selected to coincide with the actuator and measurement point locations. (While the actuator locations are fixed in this particular example the measurement points may be reassigned to coincide with a desirable set of nodes.)

The ith column of the matrix A is generated by applying a unit load at actuator location i and calculating the resulting deformations at the measurement locations. The finite element algorithm provides deformations parallel and normal to the optical axis. The normal deflections may generally be neglected for a thin shallow shell.

The figure sensor detects differences in the length of radii joining the measurement point and a reference point to the center of curvature of the spherical wavefronts emerging from the decollimator. In the case of the deformable mirror the reference point is normally selected to coincide with a point on the mirror's surface corresponding to a rigid support location. As a result the reference radius may be considered constant and the measurement provided by the figure sensor is the actual change in length of the measurement point radius.

Thus if the computed deflection parallel to the optical axis is $\hat{x}_{fk}$ at the kth measurement point at a distance d_k from the optical axis the deflection sensed by the figure sensor is

$$x_{fk} = \hat{x}_{fk} \cos \gamma_d \qquad (2.10.2)$$

where

$$\gamma_d = \sin^{-1} \frac{d_k}{R} \qquad (2.10.3)$$

The data generated by Rackley[15] and the models presented in this section do not consider this transformation and (2.10.1) and (2.10.3) should be applied to the data presented in this section in order to achieve a more exact linear model for simulation.

A number of computations were performed to obtain the flexibility matrix for the 20" NASA/MSFC active mirror which is physically described in Figs. 2.10.1 and 2.10.2. The objective here was to determine the differences, if any, between results obtained by MSFC using the NASTRAN system and the results of analysis by the ICES-STRUDL II finite element analyzer.

The finite element approach is a very powerful numerical approximation technique, but at the same time the results can be quite sensitive to the way in which the element model is defined. Since some of the mirror control algorithms are highly dependent on the accuracy of the flexibility matrix, it is of great interest to

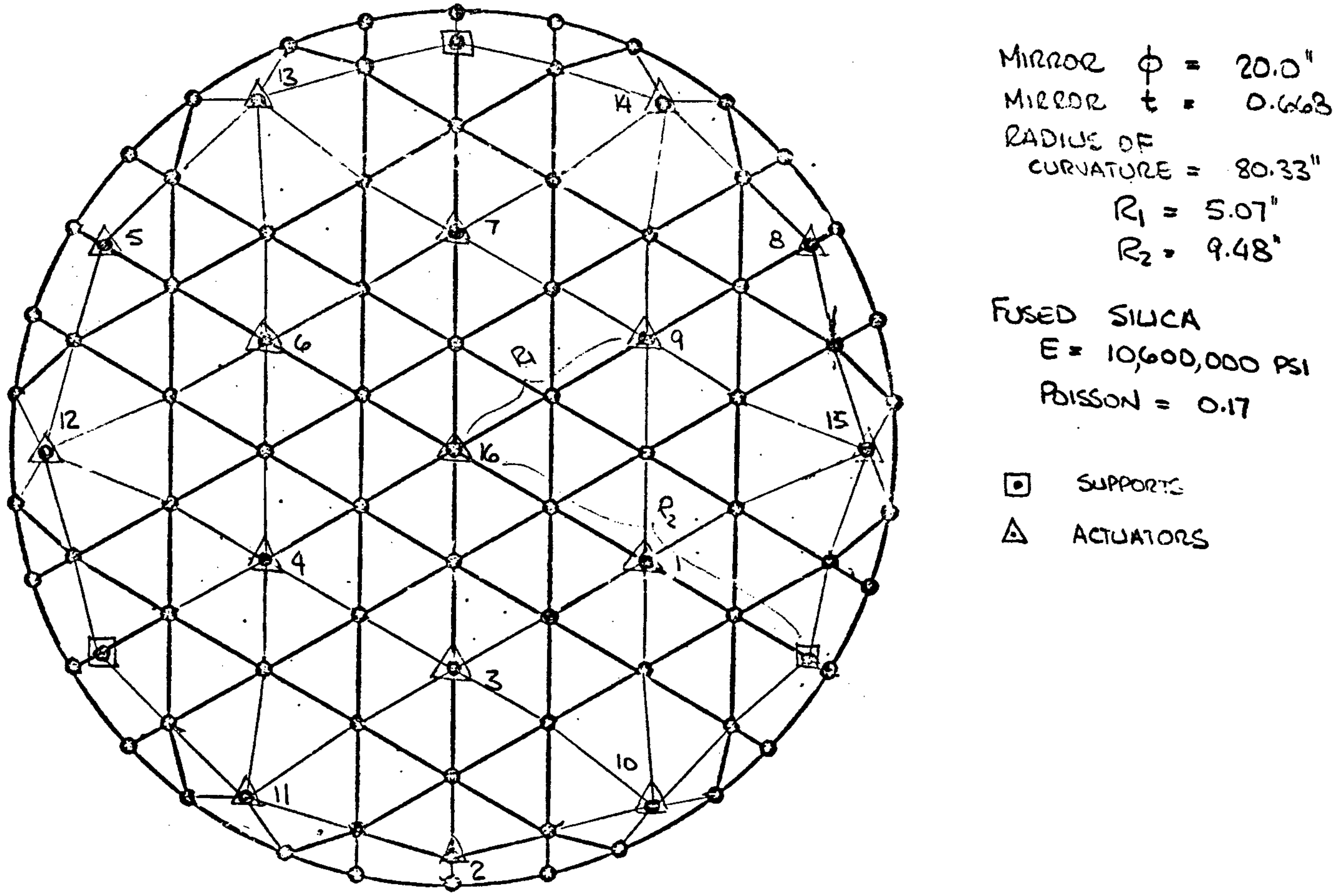
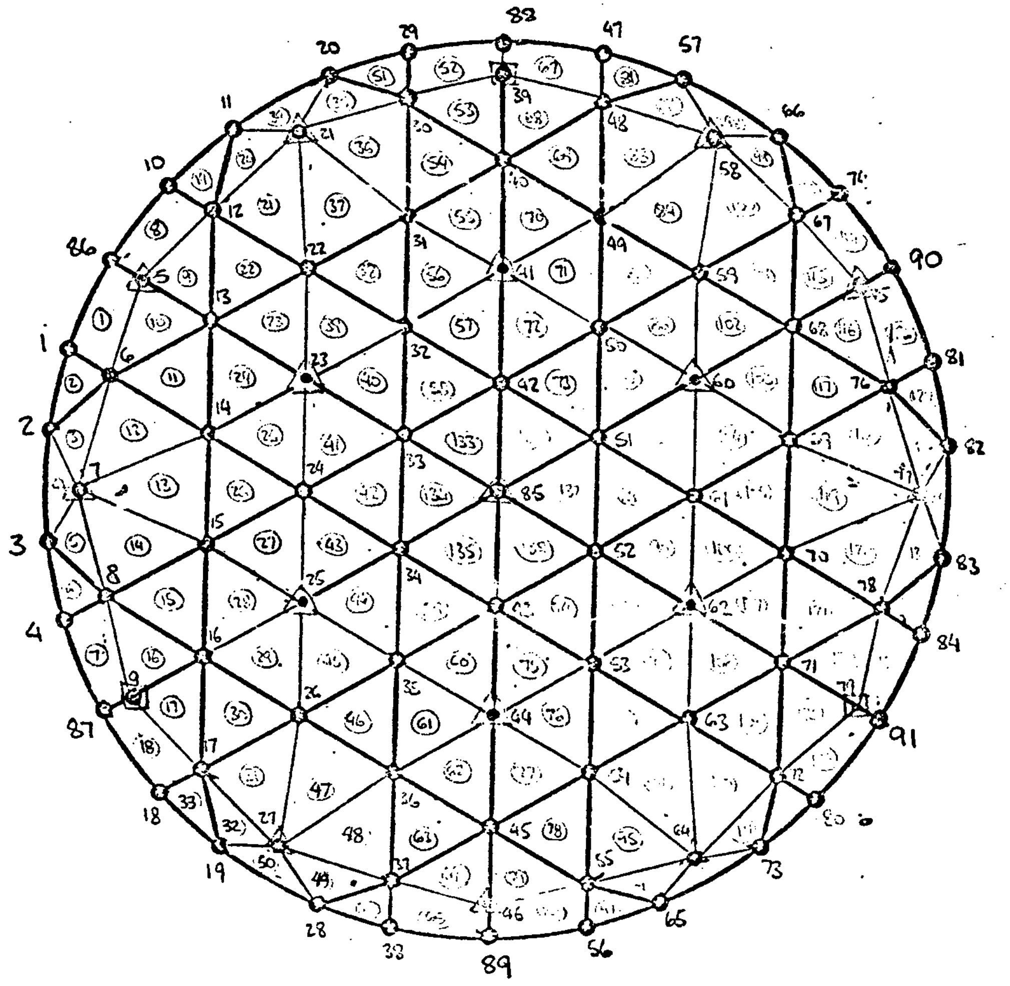


Fig. 2.10.1 Finite element deformable mirror model.



MIT Node #	MSFC Actuator #
62 46 44	1 2 3
25 5 23	4 5 6
41 75 60	7 8 9
64 27 7	10 11 12
21 58	13 14
77 85	15 16

" 10 - NODES

"⑩" - ELEMENTS

"▣" SUPPORTS

"△" ACTUATORS

Fig. 2. 10.2 Finite element deformable mirror model.

measure the possible range of errors that may be expected in the use of the finite element technique here.

2.10.2 Approach

The ideal model for finite element shell analysis involves the use of individually curved elements where the bending and stretching actions are coupled. Such elements are still, however, in the highly experimental stage and are unavailable in any of the more common large-scale analyzers, including both NASTRAN and ICES-STRUDL II. The next best approach is to use flat plates where the bending and stretching are uncoupled, but as a result, more individual elements should be used. This latter approach was the one employed by MIT/CSDL as well as NASA/MSFC.[15]

The model chosen for the studies was one using primarily triangular elements in a configuration previously tested against limiting closed-form solutions and found to perform quite satisfactorily.[16] "CPT"[17] elements were chosen for the bending triangles, and "PBQ1" for the bending quadrilaterals. The latter element is made up of four "CPT's". For the stretching components "CSTG" and "PSQ1" elements were employed. All of these elements are identical in function to the "CQUAD2" and "CTRIA2" elements found in the NASTRAN model. The number of elements used for the STRUDL study was less than with NASTRAN, but previous studies with the STRUDL model has shown that the number was already adequate.

The mirror was analyzed first as a flat plate with bending action only, then the curvature and the stretching component were included to represent the actual shell. As significant differences appeared between the STRUDL and NASTRAN shell results, the element modelling in NASTRAN (as per NASA/MSFC memo referenced above) was tested using the STRUDL system and elements. Due to funding limitations, this could be done for the bending case only.

2.10.3 Results

Table 2.10.1 summarizes the STRUDL finite element bending behavior results for the flexibility matrix. The complete matrix was recorded to simplify error detection. While there are a total of sixteen actuators,. there are only five independent ones, the behavior of the rest may be found by various symmetry conditions. In the STRUDL analysis, all sixteen were analyzed so that any unsymmetries in the modelling that had occurred by chance error could be immediately detected. The results in Table 2.10.1 are symmetrical to about an average of 0.5%.

Table 2.10.2 summarizes the results of the shallow shell representation of the mirror. Again, good symmetry has been attained, but the differences between the plate and the shell are rather striking. In general, the shell is stiffer, with the typical decrease in stiffness near a free edge which affects shells more than plates. Subsequently, the differences at the center for the plate and shell are more noticeable than at the edges. The average difference between the plate and shell deformations is about 60%.

Table 2.10.3 summarizes the results of the NASTRAN model using STRUDL elements. Symmetry is very good again, and differences between the comparable Tables 2.10.1 and 2.10.3 are in the range of one to three percent. This is approaching the best numerical range that might be expected using finite element methods. Modelling configuration therefore does not seem to contribute significant error levels.

Table 2.10.1 FINITE ELEMENT RESULTS - BENDING MODEL $(\Delta_{ij}) \times 10^{-4}$ IN/LB = DEFLECTION AT "i" FROM LOAD AT "j"

(1) ACTUATOR I.D. NO. MSFC

	B	S	A	B	C	A	S	C	A	D	D	D	D	D	C	E
I.T. PANEL #	62	46	44	25	5	23	41	75	60	64	27	7	21	58	77	85
FIG 1-#(1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 (62)	-.139	-.099	-.129	-.077	+.023	-.053	-.077	-.099	-.129	-.061	-.064	+.021	+.021	-.064	-.062	-.133
2 (46)	-.099	-.844	-.379	-.098	+.207	+.062	+.023	+.206	+.061	-.523	-.524	+.225	+.084	+.023	+.224	-.071
3 (44)	-.129	-.379	-.280	-.129	+.061	-.047	-.053	+.061	-.047	-.246	-.246	+.081	+.020	+.020	+.021	-.146
4 (25)	-.077	-.098	-.129	-.139	-.099	-.129	-.077	+.023	-.053	-.063	-.061	-.062	-.064	+.021	+.021	-.133
5 (5)	+.023	+.207	+.061	-.099	-.846	-.380	-.099	+.206	+.061	+.084	+.226	-.525	-.525	+.225	+.083	-.072
6 (23)	-.053	+.062	-.047	-.129	-.380	-.281	-.129	+.061	-.047	+.020	+.082	-.247	-.247	+.081	+.020	-.147
7 (41)	-.077	+.023	-.053	-.077	-.099	-.129	-.140	-.099	-.129	+.021	+.021	-.064	-.062	-.061	-.064	-.133
8 (75)	-.099	+.206	+.061	+.023	+.206	+.061	-.099	-.842	-.378	+.224	+.083	+.083	+.224	-.523	-.522	-.072
9 (60)	-.129	+.061	+.047	-.053	+.061	-.047	-.129	-.378	-.280	+.081	+.020	+.020	+.081	-.246	-.246	-.147
10 (64)	-.061	-.523	-.246	-.063	+.084	+.020	+.021	+.224	+.081	-.465	-.284	+.108	+.017	+.107	+.230	-.042
11 (27)	-.064	-.524	-.246	-.061	+.226	+.082	+.021	+.083	+.020	-.284	-.465	+.231	+.108	+.016	+.107	-.042
12 (7)	+.021	+.225	+.081	-.062	-.525	-.247	-.064	+.083	+.020	+.108	+.231	-.466	-.285	+.107	+.017	-.042
13 (21)	+.021	+.084	+.020	-.064	-.525	-.247	-.062	+.224	+.081	+.017	+.108	-.285	-.467	+.230	+.107	-.043
14 (58)	-.064	+.083	+.020	+.021	+.225	+.081	-.061	-.523	-.246	+.107	+.016	+.107	+.230	-.465	-.284	-.042
15 (77)	-.062	+.224	+.081	+.021	+.083	+.020	-.064	-.522	-.246	+.230	+.107	+.017	+.107	-.284	-.464	-.042
16 (85)	-.133	-.071	-.146	-.133	-.072	-.147	-.133	-.072	-.147	-.042	-.042	-.043	-.043	-.042	-.042	-.212

Table 2.10.2 FINITE ELEMENT RESULTS - BENDING & STRETCHING (SHELL) MODEL (Δ_{ij}) ×10^{-4} IN/LB

MIT ACT #	62	46	44	25	5	23	41	75	60	64	27	7	21	58	77	85
MJFC ACT. NO.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 (62)	-.076	-.047	-.058	-.026	+.011	-.015	-.026	-.047	-.058	-.033	-.027	+.010	+.010	-.027	-.033	-.054
2 (46)	-.047	-.542	-.217	-.047	+.102	+.034	+.011	+.102	+.034	-.318	-.317	+.120	+.036	+.037	+.121	-.031
3 (44)	-.058	-.217	-.153	-.058	+.034	-.011	-.015	+.034	-.011	-.138	-.137	+.046	+.011	+.011	+.046	-.060
4 (25)	-.026	-.047	-.058	-.076	-.047	-.058	-.026	+.011	-.015	-.027	-.033	-.033	-.027	+.010	+.010	-.054
5 (5)	+.011	+.102	+.034	-.047	-.541	-.217	-.047	+.101	+.034	+.036	+.120	-.317	-.317	+.120	+.036	-.031
6 (23)	-.015	+.034	-.011	-.058	-.217	-.154	-.058	+.034	-.011	+.011	+.046	-.138	-.137	+.045	+.011	-.060
7 (41)	-.026	+.011	-.015	-.026	-.047	-.058	-.076	-.048	-.058	+.010	+.010	-.027	-.033	-.033	-.027	-.054
8 (75)	-.047	+.102	+.034	+.011	+.101	+.034	-.048	-.540	-.217	+.120	+.036	+.036	+.120	-.317	-.317	-.031
9 (60)	-.058	+.034	-.011	-.015	+.034	-.011	-.058	-.217	-.153	+.046	+.011	+.011	+.046	-.138	-.137	-.060
10 (64)	-.033	-.318	-.138	-.027	+.036	+.011	+.010	+.120	+.046	-.319	-.148	+.051	+.004	+.051	+.138	-.017
11 (27)	-.027	-.317	-.137	-.033	+.120	+.046	+.010	+.036	+.011	-.148	-.318	+.137	+.051	+.004	+.051	-.017
12 (7)	+.010	+.120	+.046	-.033	-.317	-.138	-.027	+.036	+.011	+.051	+.137	-.319	-.148	+.051	+.004	-.018
13 (21)	+.010	+.036	+.011	-.027	-.317	-.137	-.033	+.120	+.046	+.004	+.051	-.148	-.319	+.137	+.051	-.018
14 (58)	-.027	+.037	+.011	+.010	+.120	+.045	-.033	-.317	-.138	+.051	+.004	+.051	+.137	-.319	-.148	-.018
15 (77)	-.033	+.121	+.046	+.010	+.036	+.011	-.027	-.317	-.137	+.138	+.051	+.004	+.051	-.148	-.318	-.018
16 (85)	-.054	-.031	-.060	-.054	-.031	-.060	-.054	-.031	-.060	-.017	-.017	-.018	-.018	-.018	-.012	-.046

Table 2.10.3 - FINITE ELEMENT RESULTS - MSFC MODEL ON ICES-STRUDL II - BENDING ACTION ONLY (Δij) ×10⁻⁴ IN/LB

JT	86	7	65	116	231	192	213	185	162	11	28	169	266	249	109	137
ACTUATOR #	1 47	2 5,6	3 6,7	4	5	6	7	8	9	10 11,12,13,14,15	11	12	13	14	15	16
1 (86)	-.139	-.096	-.127	-.075	+.023	-.052	-.075	-.096	-.127	-.061	-.062	+.021	+.021	-.062	-.061	-.131
2 (7)	-.096	-.832	-.374	-.097	+.205	+.061	+.023	+.205	+.062	-.515	-.515	+.221	+.083	+.083	+.221	-.070
3 (65)	-.127	-.374	-.278	-.127	+.061	-.046	-.052	+.062	-.045	-.243	-.243	+.080	+.020	+.021	+.020	-.144
4 (116)	-.075	-.097	-.127	-.139	-.096	-.127	-.075	+.023	-.052	-.063	-.061	-.060	-.062	+.021	+.021	-.130
5 (231)	+.023	+.205	+.061	-.096	-.830	-.373	-.096	+.205	+.061	+.083	+.221	-.515	-.514	+.221	+.023	-.080
6 (192)	-.052	+.061	-.046	-.127	-.373	-.278	-.127	+.061	-.046	+.020	+.080	-.243	-.243	+.080	+.020	-.144
(213)	-.075	+.023	-.052	-.075	-.096	-.127	-.139	-.097	-.127	+.021	+.021	-.062	-.060	-.061	-.063	-.130
8 (185)	-.096	+.205	+.062	+.023	+.205	+.061	-.097	-.832	-.374	+.221	+.083	+.083	+.221	-.515	-.515	-.070
9 (162)	-.127	+.062	-.045	-.052	+.061	-.046	-.127	-.374	-.278	+.080	+.021	+.020	+.080	-.243	-.243	-.144
10 (11)	-.061	-.515	-.243	-.063	+.083	+.020	+.021	+.221	+.080	-.458	-.279	+.105	+.018	+.105	+.225	-.041
11 (28)	-.062	-.515	-.243	-.061	+.221	+.080	+.021	+.083	+.021	-.279	-.458	+.225	+.105	+.018	+.105	-.041
12 (169)	+.021	+.221	+.080	-.061	-.514	-.243	-.062	+.083	+.020	+.105	+.225	-.458	-.279	+.105	+.018	-.041
13 (266)	+.021	+.083	+.020	-.062	-.514	-.243	-.060	+.221	+.080	+.018	+.105	-.279	-.458	+.225	+.105	-.041
14 (249)	-.062	+.083	+.021	+.021	+.221	+.080	-.061	-.515	-.243	+.105	+.018	+.105	+.225	-.458	-.279	-.041
15 (109)	-.061	+.221	+.080	+.021	+.083	+.020	-.063	-.515	-.243	+.225	+.105	+.018	+.105	-.279	-.458	-.041
16 (137)	-.131	-.070	-.144	-.130	-.070	-.144	-.130	-.070	-.144	-.041	-.041	-.041	-.041	-.041	-.041	-.210

Table 2.10.4 NASA/MSFC FINITE ELEMENT RESULTS ON NASTRAN - SAME AS TABLE I (S&E-ASTR-MA-71-104)

$(\Delta_{ij}) \times 10^{-4}$ IN/LB
SIGN CHANGED

JT #	86	7	65	116	237	192	213	185	162	11	28	169	266	249	109	137
ACTUATOR #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1 (86)	-.120															
2 (7)	-.102	-.863														
3 (65)	-.108	-.387	-.264						– SYMMETRIC –							
4 (116)	-.055	-.101	-.108	-.120												
5 (237)	+.024	+.212	+.063	-.101	-.864											
6 (192)	-.032	+.063	-.025	-.107	-.388	-.264										
7 (213)	-.055	+.025	-.032	-.055	-.101	-.107	-.120									
8 (185)	-.101	+.211	+.063	+.024	+.212	+.063	-.101	-.863								
9 (162)	-.108	+.063	-.025	-.032	+.063	-.025	-.108	-.387	-.264							
10 (11)	-.064	-.534	-.253	-.065	+.087	+.021	+.022	+.227	+.082	-.477						
11 (28)	-.066	-.534	-.253	-.064	+.228	+.082	+.022	+.086	+.021	-.290	-.477					
12 (169)	+.022	+.228	+.082	-.064	-.535	-.252	-.066	+.087	+.021	+.108	+.231	-.478				
13 (266)	+.022	+.087	+.021	-.066	-.535	-.252	-.064	+.228	+.082	+.019	+.109	-.291	-.478			
14 (249)	-.066	+.087	+.021	+.021	+.228	+.082	-.064	-.534	-.252	+.109	+.019	+.109	+.231	-.478		
15 (109)	-.064	+.228	+.082	+.021	+.086	+.021	-.066	-.534	-.252	+.231	+.109	+.019	+.109	-.290	-.477	
16 (137)	-.098	-.073	-.112	-.098	-.074	-.112	-.098	-.073	-.112	-.043	-.043	-.043	-.043	-.043	-.043	-.160

Table 2.10.4 is the NASTRAN results obtained by NASA/MSFC. This matrix should be identical to that in Table 2.10.2, but considerable differences are discernable, to a degree not covered by numerical errors. Some matrix components in Table 2.10.4 are easily twice those in Table 2.10.2, with the mean deviation in the order of about 70%. Table 2.10.4 appears to correlate much better with Tables 2.10.1 and 2.10.3 which represent the bending behavior alone, usually within 15 to 20%. It is possible that if the STRUDL shell study had been performed with the stretching component suppressed, but with a z component (as well as x and y) for the nodes, results in Tables 2.10.1, 2.10.3 and 2.10.4 might all be very close indeed.

A copy of the NASTRAN input used to generate Table 2.10.4 was obtained and examined, but no errors could be discovered that could have caused this. We are less familiar with the subtleties of NASTRAN, however, than with STRUDL. The possibility remains open, therefore, of a fundamental "bug" inside the NASTRAN system that prevents stretching action from occurring in this example.

A final confirming study should be performed, that of testing the NASTRAN shell model on STRUDL and the STRUDL models on NASTRAN, but because of funding limitations, this has not been done here.

2.10.4 Conclusions

Based on these results, it is obvious that rather large errors of presently unknown origin can creep into the finite-element modelling of shallow shells. These are especially difficult to detect if no closed-form solutions are available for reference. The configurational modelling on the other hand appeared to have relatively small effect, but the reliability of the results in absolute terms is in question.

If it is anticipated that the control algorithms are going to be sensitive to errors in the flexibility matrix, thorough, confirming studies to establish the reliability of the structural analysis results will be absolutely mandatory.

2.11 Segmented Mirror Model

A linearized model of the segmented mirror relating the figure error measurements x_f to the displacement actuator outputs m_m in the form

$$x_f = Am_m \tag{2.11.1}$$

was desired where A is an n by n_r measurement-position matrix. If the actuators associated with each segment are grouped in the form $m_m^{(1)}$, $m_m^{(2)} \ldots m_m^{(\ell)}$ and the corresponding surface deflections are identified as $x_f^{(1)}$, $x_f^{(2)} \ldots x_f^{(\ell)}$, it is apparent that (2.11.1) may be partitioned in the form:

$$\begin{bmatrix} x_f^{(1)} \\ x_f^{(2)} \\ \vdots \\ x_f^{(\ell)} \end{bmatrix} = \begin{bmatrix} A_{11} & 0 & 0 \\ 0 & A_{22} & 0 \\ & & \ddots \\ 0 & & A_{\ell\ell} \end{bmatrix} \begin{bmatrix} m_m^{(1)} \\ m_m^{(2)} \\ \vdots \\ m_m^{(\ell)} \end{bmatrix} \tag{2.11.2}$$

The linear model for the kth segment, for example, relates the kth mirror segment measurements provided by the figure sensor at $n^{(k)}$ measurement points on the surface of the kth segment to the displacement actuations $m_m^{(k)}$ at $n_r^{(k)}$ segment actuator locations. The value of $n_r^{(k)}$ is three, providing three degrees of freedom for each segment.*

The figure sensor detects the difference in the length of radii joining the figure sensor decollimator to the desired measurement point and a fixed reference location. Since the entire segment is capable of motion,

*Note that $n_r^{(k)}$ cannot be greater than three if segment deformation is to be avoided.

the reference radius cannot be considered constant, as in the case of the deformable mirror; and the effects of perturbations in the reference radius must be considered.

Consider the kth segment shown in Fig. 2.11.1. In order to simplify the analysis it is assumed that the points p_1, p_2 and p_3 lie on a sphere centered on the figure sensor decollimator. This condition is satisfied by the initial tilt alignment control system.

Suppose that the radii joining the measurement point x_{fi} and the reference point to the decollimator are identified by $R_i^{(k)}$ and $R_r^{(k)}$, respectively. Suppose that a perturbation Δm_{mj} is introduced in the jth displacement actuator. The perturbation in the ith figure error measurement is

$$\Delta x_{fi}^{(k)} = \Delta R_i^{(k)} - \Delta R_r^{(k)} \qquad (2.11.3)$$

The elements of A_{kk} may then be obtained by passing to the limit $\Delta m_{mj}^{(k)} \rightarrow 0$.

$$a_{ij}^{(k)} = \lim_{\Delta m_{mj}^{(k)} \rightarrow 0} \frac{\Delta R_i^{(k)} - \Delta R_r^{(k)}}{\Delta m_{mj}^{(k)}} \qquad (2.11.4)$$

The perturbations $\Delta R_i^{(k)}$ and $\Delta R_r^{(k)}$ may be computed by considering the segment rotation about axes joining the segment actuator locations. Translation in this philosophy are the result of the superposition of rotational effects. Since the analysis procedures involved in computing $\Delta R_i^{(k)}$ and $\Delta R_r^{(k)}$ are identical, it is sufficient to illustrate the procedure by generating $\Delta R_i^{(k)}$.

Consider the kth segment illustrated in Fig. 2.11.1 and suppose that j = 1. The perturbation $\Delta m_m^{(k)}$ will cause a rotation about points p_2 and p_3. Consider a point $x_{fi}^{(k)}$ on the surface of the mirror which is d_a distant from p_2p_3. If d_b is the distance from the actuator $m_{m1}^{(k)}$ to p_2p_3, the change in radius $R_i^{(k)}$:

$$\Delta R_i^{(k)} = \frac{d_a}{d_b} \frac{1}{\cos \gamma_1 \cos \gamma_2} \Delta m_{m1}^{(k)} \qquad (2.11.5)$$

if $\Delta m_{m1}^{(k)}$ is sufficiently small. The angles γ_1 and γ_2 are given by the expressions:

$$\gamma_1 = \sin^{-1} \frac{d_a}{2R} \qquad (2.11.6)$$

$$\gamma_2 = \sin^{-1} \frac{d_c}{R} \qquad (2.11.7)$$

where d_c is the distance between $x_{fi}^{(k)}$ and a plane perpendicular to p_2p_3 containing the center of curvature of the mirror. Computation of $\Delta R_r^{(k)}$ leads to an expression similar to (2.11.5).

$$\Delta R_r^{(k)} = \frac{d_e}{d_f} \frac{1}{\cos \gamma_3 \cos \gamma_4} \qquad (2.11.8)$$

where d_e, d_f, γ_3 and γ_4 correspond to d_a, d_b, γ_1 and γ_2 respectively. Expressions (2.11.5) and (2.11.8) may then be substituted in (2.11.4) to yield.

$$a_{i1}^{(k)} = \frac{d_a}{d_b} \frac{1}{\cos \gamma_1 \cos \gamma_2} - \frac{d_e}{d_f} \frac{1}{\cos \gamma_3 \cos \gamma_4} \qquad (2.11.9)$$

the desired element of $A^{(k)}$. A similar procedure may be used to construct the elements relating measurement errors to actuator perturbations at locations p_2 and p_3.

The computations outlined above are easily mechanized. Note that the effect of neglecting γ_1 to γ_4 is quite small for segments of aperture less than f/4. The effect of neglecting the curvature of the mirror in the d_a, d_e computation is also quite small. Thus it is probably possible to construct an adequate model of the segmented mirror from the projected x - y coordinates obtained from the segmented mirror drawings.

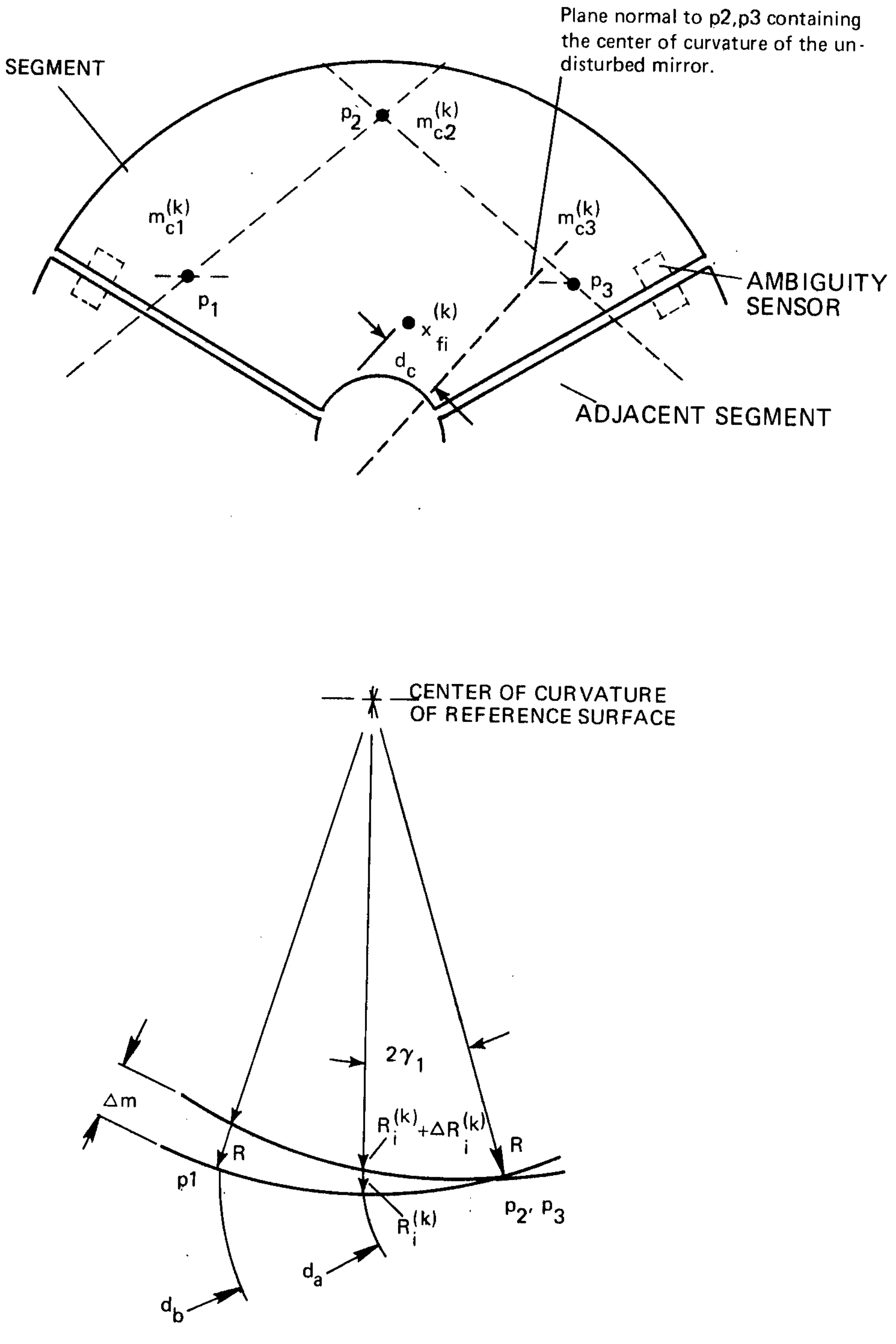


Fig. 2.11.1 Typical mirror segment geometry.

CHAPTER 3

EXPERIMENTAL ACTIVE MIRROR FIGURE CONTROL ALGORITHMS

3.1 Introduction

Figure control systems have been developed by previous investigators for two types of primary mirror structures -- segmented mirrors and deformable mirrors. Figure control in the former case is achieved by translating and rotating rigid individual mirror segments. Deformable mirror figure control is realized by elastically deforming the reflecting surface of the mirror to improve figure accuracy.

The surface accuracy achieved by figure control systems is determined by the number and arrangement of the actuators and the measurement points, the accuracy of the figure sensor, and the type of control algorithm.

Segmented mirror accuracy is ultimately limited by the figure accuracy of the individual segments which can be quite high as a result of the relatively small size of each segment. The development of large active segmented mirrors is hampered, however, by the problems associated with the accurate fabrication of off-axis surfaces of rotation.

Active deformable mirror figure accuracy is ultimately limited by the number and the geometric arrangement of the figure actuators.

The goal of current figure control systems is to achieve an rms figure accuracy of 30 nm ($\approx\lambda/20$ at 632.8 nm) which would provide diffraction-limited performance throughout most of the visible spectrum.

Two classes of figure control algorithms have emerged. The first treats the mirror as a static body -- depending on inherent mechanical damping to eliminate vibrations induced by disturbances and actuator motion. The static representation has been used by previous investigators[1, 6, 7, 13] to control deformable and segmented mirrors and is probably an adequate approach for the space telescope as a result of the low frequencies associated with the disturbances acting on the mirror.[1] Theoretical studies have also been performed to develop algorithms which provide active control of the dynamical bending modes of the mirror.[14] The modal control approach places severe bandwidth requirements on the control systєm and complicates the problem of actuator placement. The following systems describe algorithms which have been developed at MIT/DL to control the mirror figure in the static sense.

3.2 Deformable Mirror Control Laws

Suppose that the error between that actual figure and the ideal figure is evaluated on the surface of the mirror at n discrete points. The errors may be conveniently expressed as elements of an array x_f.

The figure of the primary mirror is controlled by elastic deformation achieved by applying an array of n_r loads m_m to the rear of the mirror which is rigidly supported at three points. If the initial figure errors ($m_m = 0$) at the n measurement points are associated with the array x_d, the net figure errors at the n points may be written:

$$x_f = x_d + A_r m_m \qquad (3.2.1)$$

where A_r is a reduced deformation-force matrix.

In order to develop a control strategy it is useful to define a performance index. A useful index is the unbiased root mean square figure error:

$$J_m = \left[\frac{1}{n} x_f' x_f\right]^{1/2} \qquad (3.2.2)$$

This performance index is minimized if the control force m_m is of the form:

$$m_m = -\left[A_r' A_r\right]^{-1} A_r' x_d \qquad (3.2.3)$$

Such a control is the linear optimal control for the system (3.2.1) with the performance index (3.2.2). The resulting figure is a best least squares fit to the ideal reflecting surface. Note that the control in (3.2.3) requires the measurement of n errors ($n > n_r$) in order to compute the n_r figure controls.

A special case of (3.2.3) occurs if $n = n_r$ in which case the figure errors at all n_r locations may be reduced to zero. The required control in this case is:

$$m_m = -A_{rr}^{-1} I_r x_d \tag{3.2.4}$$

where I_r is a reduced identity matrix which maps the n figure measurements into n_r measurements. This control strategy has been used by other investigators and is referred to here as the simplified linear control.

The above controls are special cases of the general linear control law of the form:

$$m_m = -K_g x_d \tag{3.2.5}$$

The linear optimal and simplified linear gain matrices are differentiated by subscripts:

$$K_o = \left[A_r' A_r\right]^{-1} A_r' \tag{3.2.6}$$

$$K_\ell = A_{rr}^{-1} I_r \tag{3.2.7}$$

3.3 Segmented Mirror Control Laws

Segmented mirror figure control is achieved by translating and rotating each segment by means of three position actuators. It is convenient to represent the position controls as elements of an array m_m in which case the figure error x_f may be written:

$$x_f = x_d + A_r m_m \tag{3.3.1}$$

where x_d is the initial figure error and A_r is a linear transformation relating the actuator position changes to a corresponding change in the monitored figure errors.

In light of the similarity between equations (3.2.1) and (3.3.1) it is apparent that identical control laws are applicable to the segmented and deformable mirrors. Thus the simplified linear K_ℓ and linear optimal K_o control gain matrices for the segmented system are:

$$K_o = \left[A_r' A_r\right]^{-1} A_r' \qquad (3.3.2)$$

$$K_\ell = A_{rr}^{-1} \qquad (3.3.3)$$

where A_{rr} is the doubly reduced model matrix for the segmented mirror.

3.4 Discrete Control Algorithm for Mirror Figure Control

Sections 3.2 and 3.3 have described the mathematical properties of the figure control laws. In order to achieve this control it is necessary to develop a discrete algorithm for digital computer realization. A simplified block diagram of the digital figure control system is shown in Fig. 3.4.1. A complete set of figure error data is sampled every t_s seconds. The figure control algorithm operates on the figure error to produce a set of desired actuator outputs m_c. The actuator commands m_c provide inputs to a digital figure actuator control system with a cycle time Δt. The figure control computation cycle time t_s is an integral multiple of Δt. The actuator control system operates to assure that outputs m_m are approximately equal to the actuator commands m_c. This

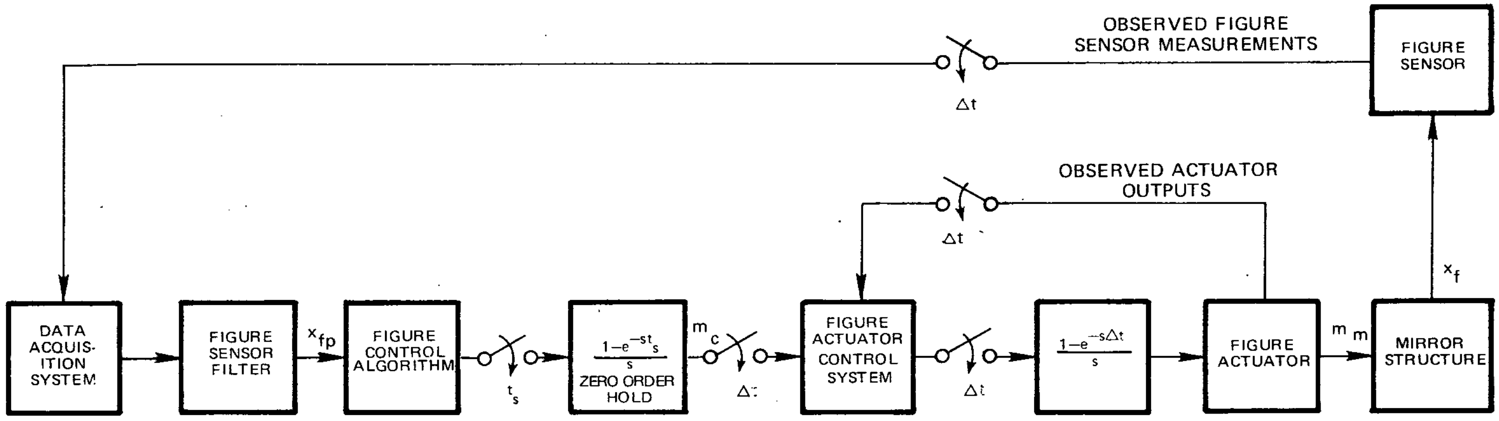


Fig. 3.4.1 Simplified diagram of the digital active mirror control system.

implementation of the EAM figure control is classified as a multirate sampled data system.

The time interval t_s between successive computations of m_c is determined by a number of considerations including the response time of the figure sensor and the dynamic response characteristics of the mirror structure and figure actuators.

The figure sensor currently incorporated in the EAM is a serial measuring device inasmuch as the figure error can only be measured one point at a time.* Limitations in the design of the piezoelectric interferometer path difference modulator and the phase detector filter time constant limit the minimum observation time at each measurement point, as indicated in Table 2.2.1, to approximately 0.2 seconds.

Operation of the figure actuators excites a damped vibration in the mirror structure. As a result of the serial nature of the figure sensor it is necessary to wait until the vibration has decayed below an acceptable level before measuring the figure error.

The dynamic response time of the actuators is determined by the bandwidth of the actuator control systems. The digital character of the actuator control systems will mean that the choice of Δt will play a strong role in determining minimum response time.

The EAM digital control system accounts for the dynamical characteristics of the EAM components by realizing the operation

* Other versions of the figure sensor utilize a photodiode array to permit parallel processing of figure error data.

sequence shown in Fig. 3.4.2. A control cycle is initiated by a period n_{wait} cycles long during which the actuators respond to the actuator commands. The number of cycles n_{wait} should be large enough to permit the actuators to reach an essentially steady state. At the end of the actuator control interval the actuator outputs are frozen, and the image dissector is positioned to the first measurement location. The measurement sequence consists of positioning the image dissector, a pause of n_{pos} cycles during which transients in the phase detector output are allowed to settle followed by a sequence of n_{meas} phase detector filter output measurements at intervals of n_{mint} cycles. The position, n_{pos} cycle wait, n_{mint} wait, measure, n_{mint} wait ... sequence is repeated at each of the n measurement points. At the completion of measurements the figure sensor data are processed to reduce noise and eliminate ambiguities and a new set of actuator commands m_c computed. The actuators are then activated to initiate another control cycle.

The discrete figure control algorithm is currently implemented in the form:

$$m_c(i+1) = m_c(i) + \beta_k K x_{fp}(i) \qquad (3.4.1)$$

where $m_c(k)$ and $x_{fp}(k)$ are the values of actuator commands m_c and the processed figure error measurements x_{fp} at time t_k where:

$$t_{k+1} = t_k + t_s \qquad (3.4.2)$$

A description of the figure sensor filter is given in Section 3.5. The scalar factor β_k is given by the relation:

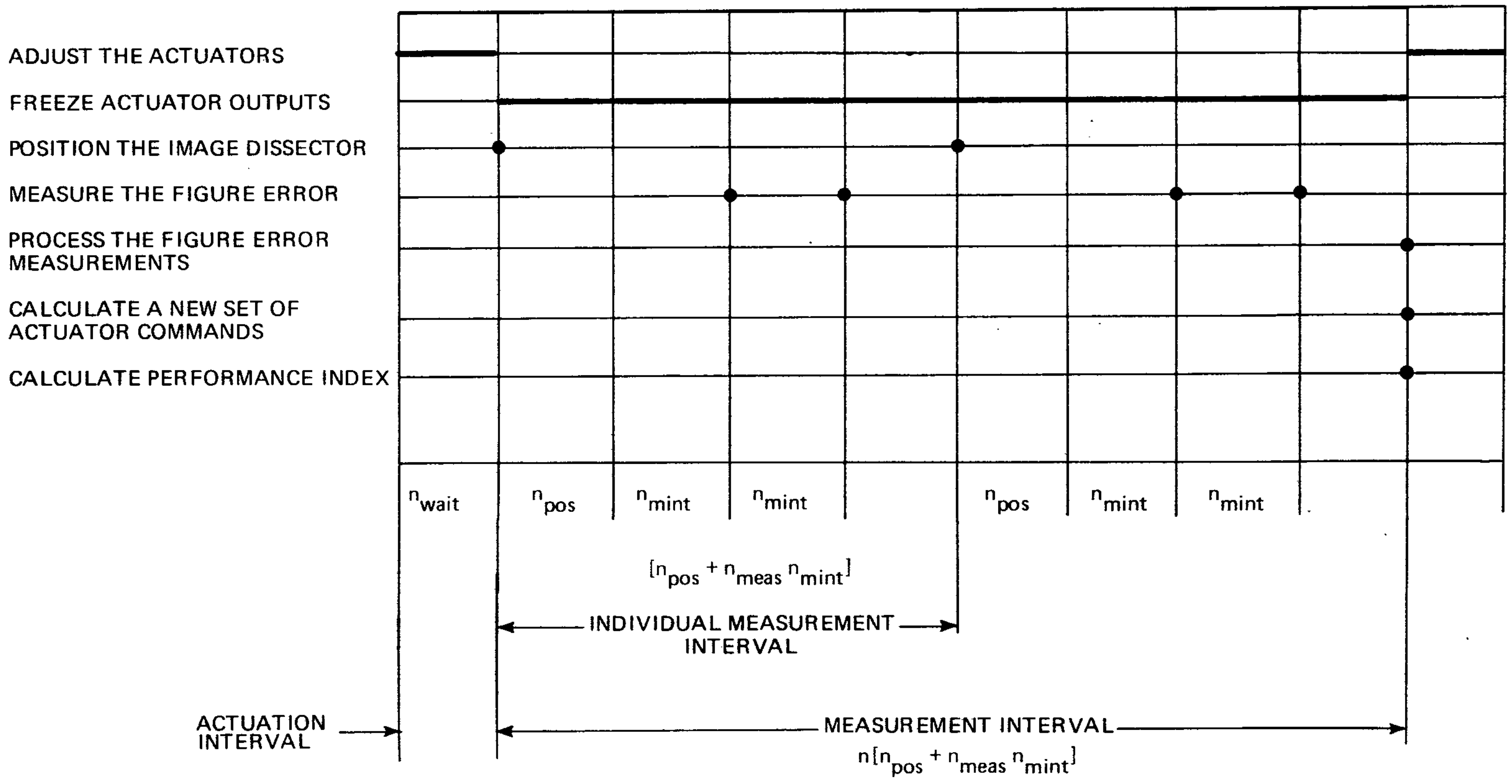

ADJUST THE ACTUATORS
FREEZE ACTUATOR OUTPUTS
POSITION THE IMAGE DISSECTOR
MEASURE THE FIGURE ERROR
PROCESS THE FIGURE ERROR MEASUREMENTS
CALCULATE A NEW SET OF ACTUATOR COMMANDS
CALCULATE PERFORMANCE INDEX
n_{wait}
n_{pos}
n_{mint}
n_{mint}
n_{pos}
n_{mint}
n_{mint}
$[n_{pos} + n_{meas} n_{mint}]$
INDIVIDUAL MEASUREMENT INTERVAL
ACTUATION INTERVAL
MEASUREMENT INTERVAL
$n[n_{pos} + n_{meas} n_{mint}]$

Fig. 3.4.2 Figure control system timing diagram.

$$\beta_k = \beta_g t_s \tag{3.4.3}$$

where β_g is a scalar constant. This choice for β_g assures that the dynamic response characteristics of the control system will be relatively independent of changes in t_s.

The feedback gain matrix K may be K_o, K_ℓ or a general gain matrix K_g. If $\beta_k = -1$ and $m_c(0) = 0$, the computed value m_c will equal the desired control:

$$m_c(1) = -K_g x_d \tag{3.4.4}$$

after one interation. Values of $-1 < \beta_k < 0$ result in a solution which slowly converges to the desired control.[1.]

3.5 Figure Sensor Data Processing Algorithm

Ambiguities in figure measurement which occur whenever the magnitude of the figure error equals $\frac{\lambda}{4}[1 + 2i]$ where i is an integer limit the effective measurement range of the figure sensor to $\pm\frac{\lambda}{4}$. Since the initial figure magnitude could easily exceed $\frac{\lambda}{4}$*, a digital signal processor was developed which would extend the effective operating range. The resulting algorithm reduces sensor noise in addition to eliminating measurement ambiguity.

The inspiration behind the figure sensor filter design may be obtained by observing certain statistics associated with the figure sensor filter outputs. Suppose that a sequence of points is defined on the surface of the mirror in such a way that the error at each

* If aspheric figure control is desired, the difference between the reference sphere and the desired figure can be many wavelengths. Measurement of an aspheric surface may be accomplished using the technique presented here or an optical data processing procedure such as the moire´ fringe technique.[8]

point satifies the relationship:

$$x_{fi} = i\Delta_f \qquad (3.5.1)$$

where Δ_f is a positive number $<< \frac{\lambda}{4}$. That is, the error at the points increases in a linear fashion. Such a situation may be achieved, in practice, by defining a set of measurement points equidistantly spaced or on a straight line and then slightly tilting the mirror about an axis perpendicular to the optical axis and the straight line. If the figure control system is required to perform a sequence of measurements on the points (3.5.1), the outputs of the figure sensor as a function of time will appear as shown in Fig. 3.5.1 which delineates the figure error input β_{xf}, figure sensor noise β_{nf}, phase detector input β_{xa}, output β_p filtered output β_f and rms value β_{mrf} calculated at each measurement location where:

$$\beta_{mf} = \frac{1}{n_{meas}} \sum_{i=1}^{n_{meas}} \beta_{fi} \qquad (3.5.2)$$

$$\beta_{mrf} = \left[\frac{1}{n_{meas}} \sum_{i=1}^{n_{meas}} \left(\beta_{fi}^2 - \beta_{mf}^2 \right) \right]^{1/2} \qquad (3.5.3)$$

and β_{fi} is the ith filter output sample at each position. Note that β_{mrf} increases whenever a switching boundary ($\beta_{xf} = \frac{\lambda}{4}(1 + 2k)$; k an integer) is approached. This property is used advantageously to detect an ambiguous measurement range by defining a decision threshold β_{ft} on β_{mrf}.

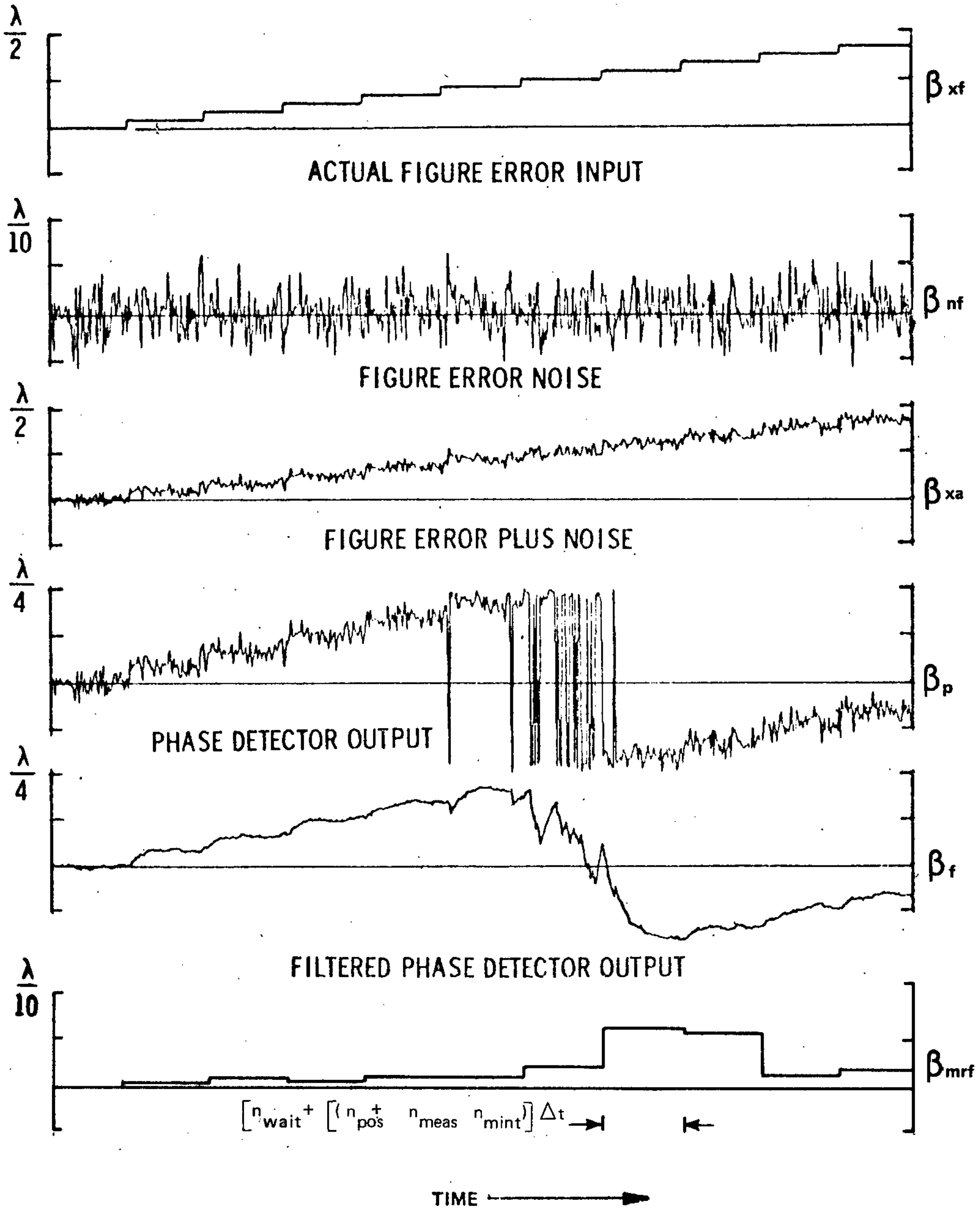


Fig. 3.5.1 Typical figure sensor simulation results.

A flow diagram of the figure sensor data processing algorithm is shown in Fig. 3.5.2. This algorithm is valid for measurement errors in the range $|\beta_{xa}| < \frac{3\lambda}{4}$ where λ is the laser wavelength (632.4 nm). An extension in range is easily accomplished by modifying the switching boundary and ambiguity factor computations. The limited range was adopted to simplify coding and to save computation time during simulation.

The initial measurement point should be selected so that $\beta_{mrf} < \beta_{ft}$. Subsequent computations provide values of the processed figure error relative to the first location.

If $\beta_{mrf} < \beta_{ft}$ at a measurement point, the figure error is calculated by adding the mean value β_{mf} of the n_{meas} measurements to the ambiguity factor β_{ab} which is initially zero. The computed value x_{fpi} is stored in $\beta_{\ell f}$ for future reference. The nearest switching boundary is also calculated for use when an ambiguous measurement is perceived.

If the rms value of the measurements exceeds β_{ft} at the ith location, an ambiguous measurement problem is identified and the processed figure error is calculated by linear extrapolation about the closest switching boundary β_{sw}. The extrapolation constant β_z is read in by the program. The ambiguity factor is calculated if the value of β_{mf} has changed sign and the magnitude of the product of the old value of β_{mf} and its current value is greater than β_{ts}. This test prevents the generation of spurious ambiguity factor values which would arise if $\beta_{mf} \approx 0$.

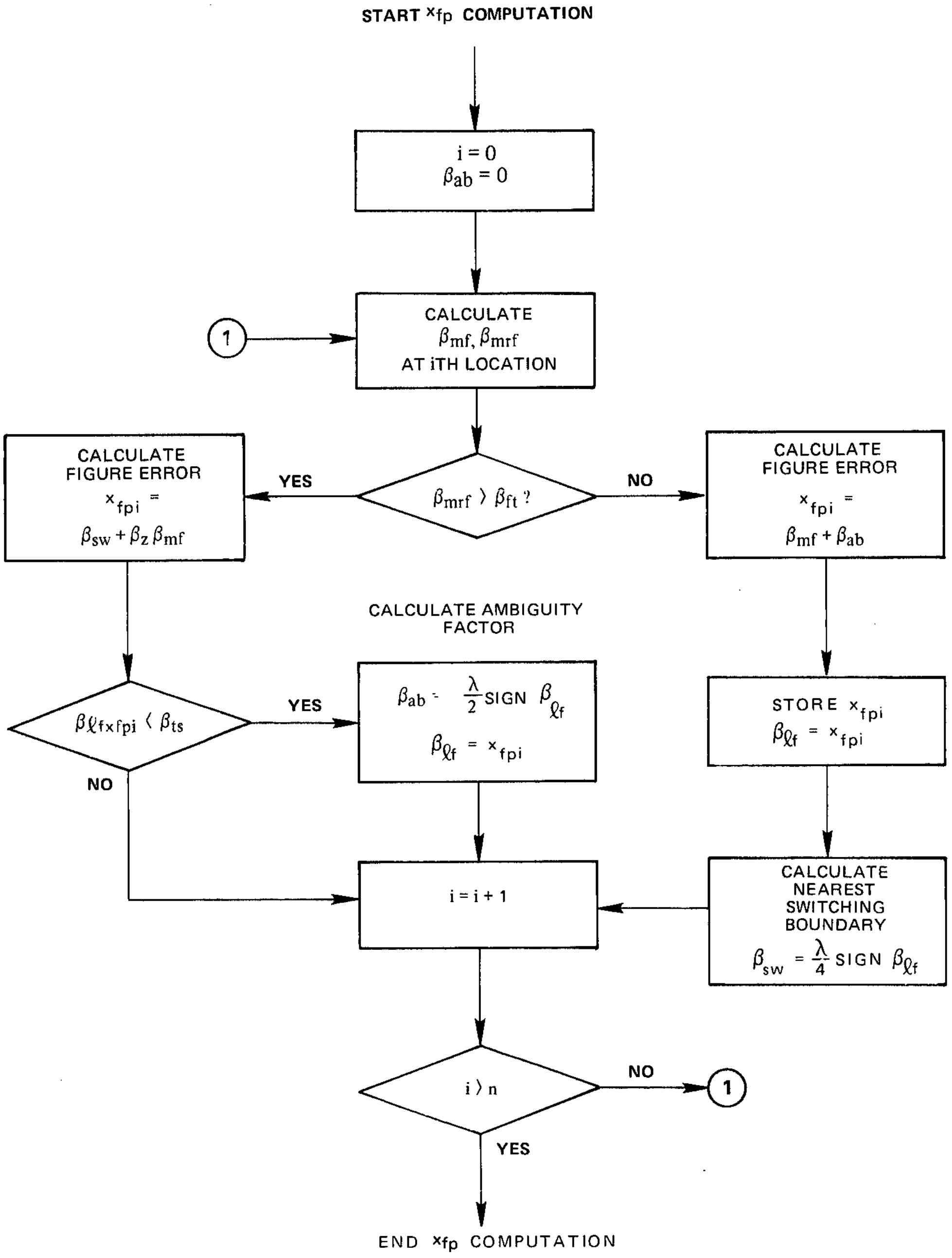

START x_{fp} COMPUTATION
$i = 0$
$\beta_{ab} = 0$
1
CALCULATE β_{mf}, β_{mrf} AT iTH LOCATION
$\beta_{mrf} > \beta_{ft}$?
YES
NO
CALCULATE FIGURE ERROR $x_{fpi} = \beta_{sw} + \beta_z \beta_{mf}$
CALCULATE FIGURE ERROR $x_{fpi} = \beta_{mf} + \beta_{ab}$
CALCULATE AMBIGUITY FACTOR
$\beta_{\ell f x fpi} < \beta_{ts}$
YES
NO
$\beta_{ab} - \frac{\lambda}{2}$ SIGN $\beta_{\ell f}$
$\beta_{\ell f} = x_{fpi}$
STORE x_{fpi}
$\beta_{\ell f} = x_{fpi}$
$i = i + 1$
CALCULATE NEAREST SWITCHING BOUNDARY $\beta_{sw} = \frac{\lambda}{4}$ SIGN $\beta_{\ell f}$
$i > n$
NO
1
YES
END x_{fp} COMPUTATION

Fig. 3.5.2. Figure sensor data processing algorithm.

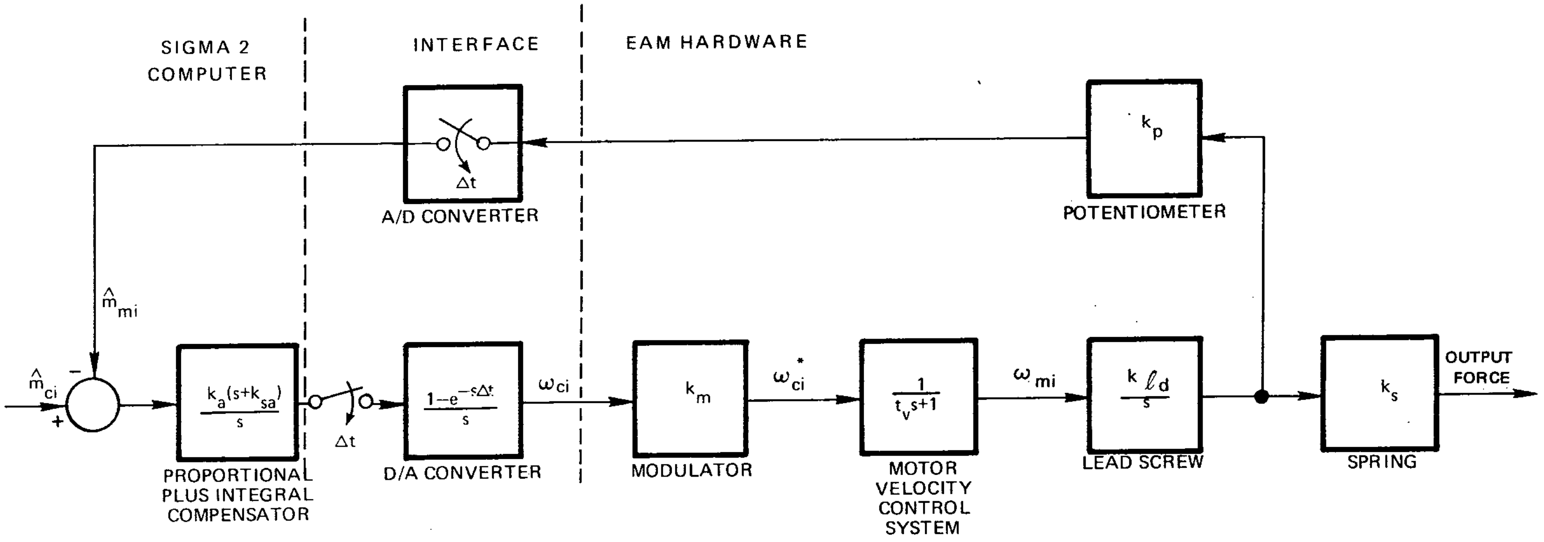


Fig. 3.6.1 Force actuator control algorithm.

Sensor noise is reduced by the averaging process performed during the computation of β_{mf}. If the sample period is long compared to the figure sensor time constant and the noise source is uncolored, the rms noise level is reduced by the reciprocal of the square root of n_{meas}.

3.6 Force Actuator Control System

A block diagram of the ith force actuator control algorithm is shown in Fig. 3.6.1. The actuator output force m_m is regulated by controlling the extension of a spring. The sensed ith spring extension $\hat{m}_{mi}$ is compared with the desired spring extension $\hat{m}_c$ and the resulting error signal processed to provide the motor velocity command ω_c. Proportional plus integral compensation is used to eliminate steady state position errors. The position command $\hat{m}_{ci}$ is obtained by operating on m_{ci} which is calculated by the discrete control law (3.4.1)

$$\hat{m}_{ci} = m_{ci} m_{gi} \tag{3.6.1}$$

where m_g is an input vector of scale factors.

3.7 Position Actuator Control System

The position actuator control system is shown diagramatically in Fig. 3.7.1. The actuator position command is scaled using equation (3.6.1) to produce $\hat{m}_c$. The pulse modulator produces a pulse every time a new control is calculated. The area of the pulse is selected so that the resulting change in actuator position equals the desired change in position δm_{ci}:

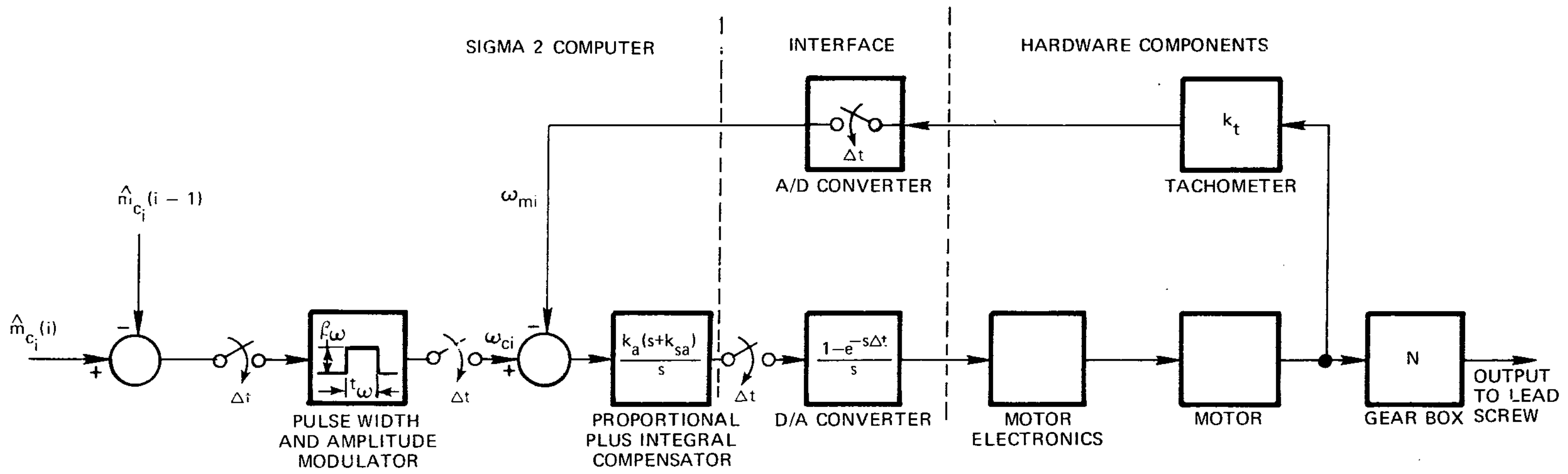


Fig. 3.7.1 Position actuator control system.

$$\delta m_{ci}(i) = m_{ci}(i) \qquad (3.7.1)$$

thus β_ω and t_ω must be selected so that

$$\frac{NK_{\ell d}K_{s_1}K_{s_2}}{K_t}\beta_\omega t_\omega = \delta m_{ci}\, m_{gi} \qquad (3.7.2)$$

Further constraints are imposed by requiring t_ω to be an integral multiple of Δt:

$$t_\omega = n_\omega \Delta t \qquad (3.7.3)$$

With this restriction β_ω becomes:

$$\beta_\omega = \frac{\delta m_{ci} m_{gi} K_t}{NK_{\ell d}K_{s_1}K_{s_2} n_\omega \Delta t} \qquad (3.7.4)$$

If m_{gi} is selected so that:

$$m_{gi} = \frac{NK_{\ell d}K_{s_1}K_{s_2}}{K_t} \qquad (3.7.5)$$

the computation for β_ω becomes:

$$\beta_\omega = \frac{\delta m_{ci}}{n_\omega \Delta t} \qquad (3.7.6)$$

n_ω is read in as part of the input data and must satisfy the relationship:

$$n_\omega \le n_{wait} \qquad (3.7.7)$$

Small values of n_ω lead to large commanded rates.

Note that this implementation does not include the motor velocity feedback loop signal processing filter included in the original position actuator control system.[13] This omission was made because the digital control system does not impose severe response requirements on the velocity servomechanism.

3.8 Initial Active Mirror Alignment

The final alignment procedures described above are only applicable after the mirror figure has been approximately aligned relative to the figure sensor. Initial alignment is performed in two stages. The first stage consists of tilting the mirror or mirror segment until three designated non-collinear points on its surface lie on the surface of a sphere centered on the image sensor decollimator. The second stage of adjustment moves the mirror in an axial fashion until the distance to the decollimator focus equals the radius of curvature of the mirror. The latter adjustment is less sensitive than the former. Tilt and axial control adjustments can be repeated a number of times until satisfactory alignment is achieved.

The initial alignment control systems for the deformable mirror are included in the deformable mirror electronics and are not discussed here. The alignment algorithms for the segmented mirror were implemented as part of the software package and are discussed in the following sections.

3.9 Tilt Alignment System

Each segment of the segmented active mirror is equipped with three actuators which permit segment motion in three degrees of freedom. The actuator deflections associated with the jth segment are conveniently identified by the elements m_{mj_1}, m_{mj_2} and m_{mj_3} of the actuator output vector m_m. The corresponding x, y position coordinates on the figure surface are identified x_{j_1}, y_{j_1}, x_{j_2}, y_{j_2}, and x_{j_3}, y_{j_3}. Suppose that it is desired to tilt the mirror so that the figure errors at the actuator locations are all zeros. Tilt alignment is achieved by the following sequence of operations:

1. Drive the figure error at x_{j_1}, y_{j_1} to zero using actuator m_{mj_1}.
2. Measure the figure error at position $(1 - i\Delta)x_{j_1} + i\Delta x_{j_2}$, $(1-i\Delta)y_{j1} + i\Delta y_{j2}$ where $\Delta = n_{tilt}^{-1}$, and adjust actuator m_{mj_2} to drive the error to zero.
3. Repeat step 2 for increasing values of i = 1, 2, 3 ... n_{tilt}.
4. Simultaneously perform steps 2 and 3 for position x_{j_3}, y_{j_3} using actuator m_{mj_3}.

At the end of step 4 the errors at all three actuator positions will be zero.

The tilt control algorithm was realized by modifying the program data so that the existing control structure could be utilized for both tilt

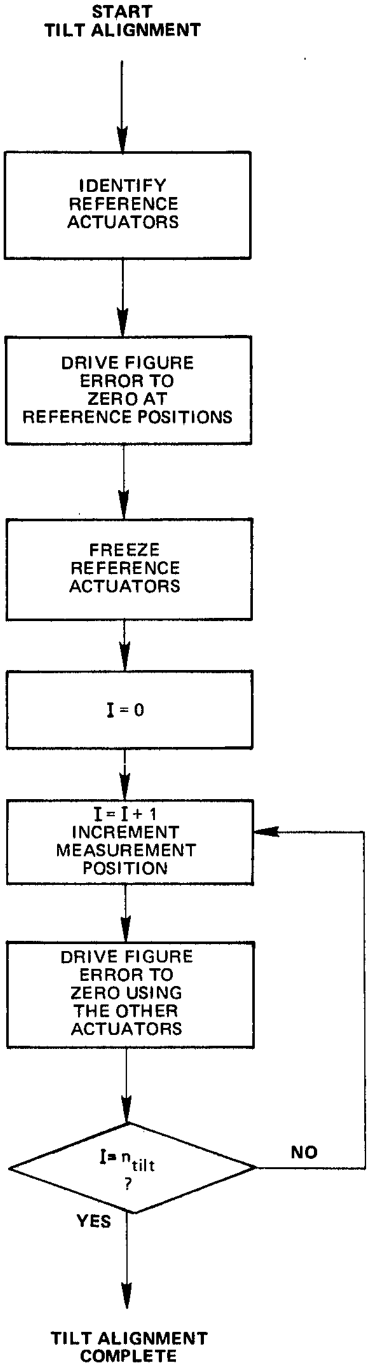


Fig. 3.9.1 Tilt alignment algorithm.

control and fine mirror figure adjustments. The actual tilt alignment program, illustrated in Fig. 3.9.1, performs steps 1-4 for all three segments simultaneously.

3.10 Slew Alignment Algorithm

Once the segments have been aligned in tilt, the three measurement points on each segment corresponding to the actuator locations will lie on a spherical surface centered on the center of curvature of the spherical wavefronts emerging from the decollimator. However, there is no assurance that all the measurement points will lie on a sphere of uniform curvature as a result of possible axial misalignment. In order to correct this problem the segmented mirror is equipped with an adjacent edge ambiguity sensor* which provides a measure of the relative axial segment position. The output of the ambiguity sensor is a maximum when the adjacent segment edges are at the same radius from the figure sensor. A disparity in edge alignment results in a reduction in sensor output monotonically related to the magnitude of the error in a useful range of ± 600 nm.

In order to correct errors in axial segment position a simple algorithm was developed. The control algorithm produces a sequence of axial position commands which converge to the position which maximizes the ambiguity sensor output.

Suppose that the output of the sensor between the reference segment j and segment k is identified as α_{jk} and the corresponding axial position command to the segment k actuators is α_{mk}. A simple algorithm which produces a sequence of α_{mk} which maximize

* white light interferometer

α_{jk} is shown in Fig. 3.10.1. This algorithm is based on the method of steepest descent. The variable α_d is a dummy variable. The parameters NHC and NIC keept track of the number of step size halvings and successful iterations respectively. An iteration is successful if the ambiguity sensor output is increased. The step size is halved if a zero or negative change in α_{sa} occurs. Computation is terminated if NHC equals NHM or NIC equals NIM where NHM and NIM are input variables.

The axial alignment control system is realized so that the axial positions of two segments are simultaneously adjusted with respect to the third segment which serves as a position reference.

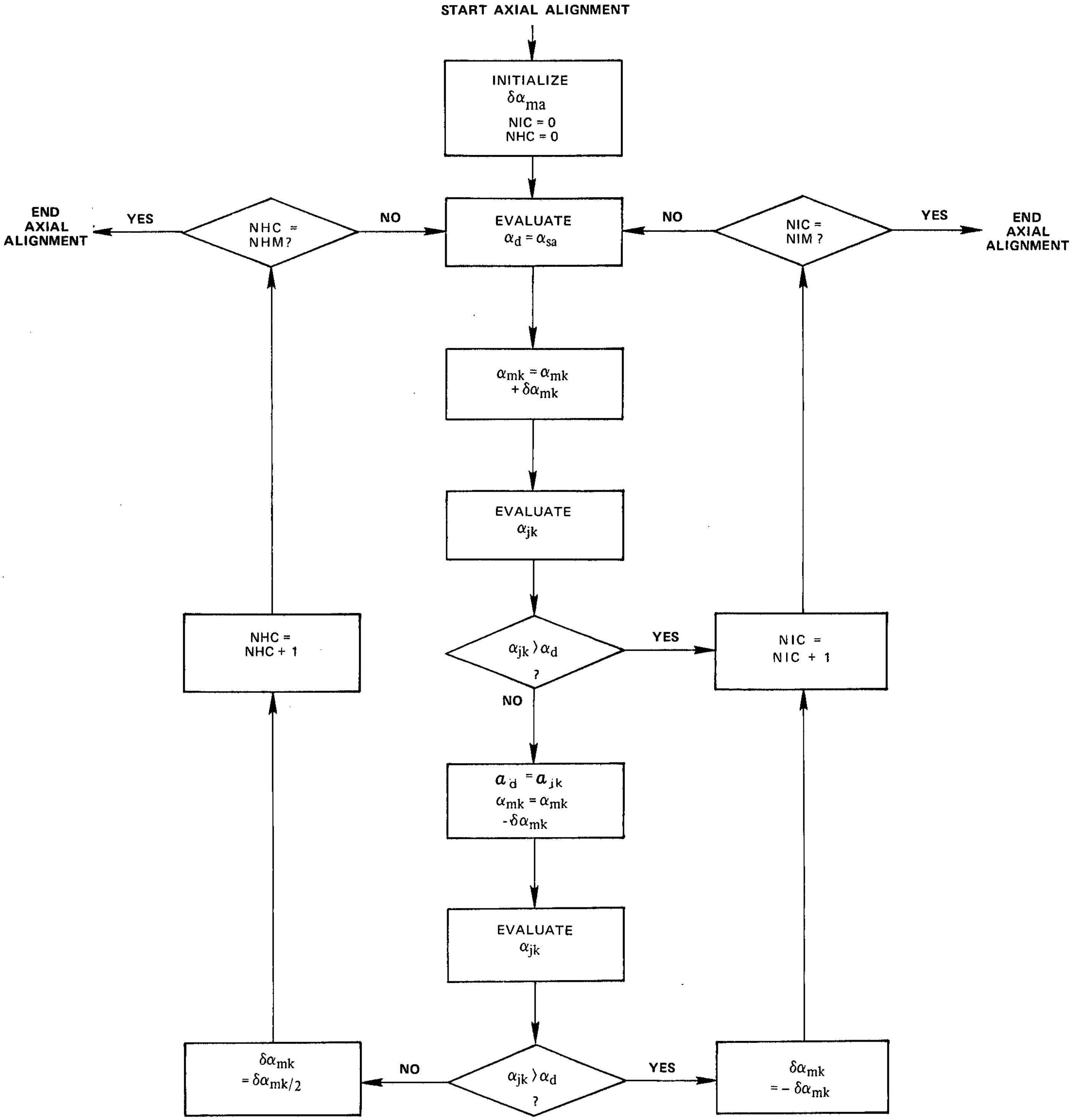

START AXIAL ALIGNMENT
INITIALIZE $\delta\alpha_{ma}$ NIC = 0 NHC = 0
END AXIAL ALIGNMENT
YES
NHC = NHM?
NO
EVALUATE $\alpha_d = \alpha_{sa}$
NO
NIC = NIM ?
YES
END AXIAL ALIGNMENT
$\alpha_{mk} = \alpha_{mk} + \delta\alpha_{mk}$
EVALUATE α_{jk}
NHC = NHC + 1
$\alpha_{jk} \rangle \alpha_d$?
YES
NIC = NIC + 1
NO
$a_d = a_{jk}$ $\alpha_{mk} = \alpha_{mk} - \delta\alpha_{mk}$
EVALUATE α_{jk}
$\delta\alpha_{mk} = \delta\alpha_{mk/2}$
NO
$\alpha_{jk} \rangle \alpha_d$?
YES
$\delta\alpha_{mk} = - \delta\alpha_{mk}$

Fig. 3.10.1 Slew control system algorithm.

CHAPTER 4

EXPERIMENTAL ACTIVE MIRROR SOFTWARE

4.1 Introduction

The software of the EAM was written in FORTRAN, permitting execution on a wide variety of computers. Development and initial checkout were performed on an IBM 370/155, and final checkout was completed on an XDS Sigma 5/7 at MSFC. Software to be used in the XDS Sigma 2 was written in a simplified FORTRAN (370/155, Sigma 5/7 compatible) to accommodate the limitations of the Sigma 2 FORTRAN monitor.

The software consists of two sections; the first is designed for residence in the Sigma 5 where the complicated EAM control computations are performed on a time-shared basis; the second resides in the Sigma 2 and provides real-time control of the EAM hardware.

The architecture of the most important software elements is illustrated in Fig. 4.1.1. The main programs resident in the Sigma 5 and the Sigma 2 are designated SUPE5 and SUPE2 respectively.

The major hardware component control functions are performed by routine EAMCS via the figure sensor FIGSEN, actuator ACTCMD, and remote terminal TYPCON supervisory subroutines. While figure error measurement and actuator command execution are performed in the Sigma 2, figure data processing and figure control computation are performed in MAINA which is interrogated by EAMCS. The capabilities of MAINA are extended by subroutine MAINC.

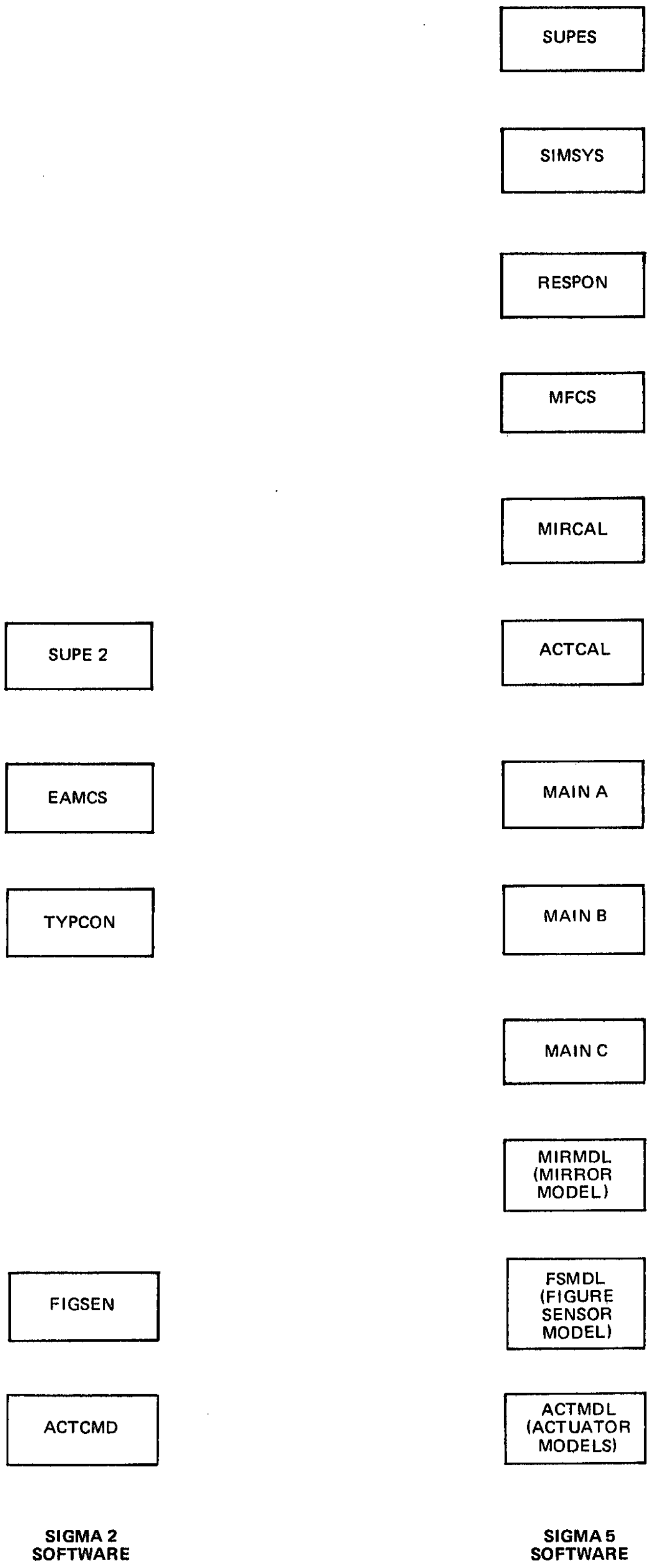


Fig. 4.1.1 Major EAM software components.

Data input control is primarily provided by routines SIMSYS and RESPON which, in addition, provide the basic software structure for active mirror simulation. Most of the data for the EAM control system and hardware models is read in by MFCS which also provides coding for the computation of the gain matrices K_o and K_ℓ.

Models for the mirror structure, figure sensor and actuator are provided by MIRMDL, FSMDL, and ACTMDL respectively.

Subroutines MIRCAL and ACTCAL provide software for experimentally evaluating the reduced structural model matrix of the mirror and checking the actuators for correct operation via actuator command perturbation and EAMCS.

Diagnostic and parameter modification functions using the remote terminal are provided by the combination of TYPCON in the 2 which operates the terminal and MAINB in the 5 which provides the coding required to perform the desired operations.

The software is designed to provide three major operating configurations determined by input operating mode control parameters (MODV, see section 5.2.1).

1. Experimental active mirror simulation using the real-time control system software and hardware models. All program components are resident in the Sigma 5/7.
2. Experimental active mirror simulation using the real-time control system software resident in the Sigma 2.
3. Experiment operation using the Sigma 5 for complex control computations on a when-available-basis and a real-time hardware control system resident in the Sigma 2.

Operating configurations 1 and 2 are illustrated in Fig. 4.1.2 which shows the calling priorities[*] in the simulation mode. In configuration 1 all the software modules are resident in the Sigma 5 as indicated by boundary "A." It is also possible to simulate the active mirror using both the Sigma 5 and Sigma 2 computers as indicated by boundary "B." In this case all transfers across boundary "B" are completed using SUPE5 and SUPE2 as explained in sections 5.2 - 5.4.

The calling priorities in the experiment operating mode are delineated in Fig. 4.1.3. Experiment control is transferred to the remote console via EAMCS and TYPCON. Once the experiment is started it will continue to operate for NTIMSQ cycles unless it is interrupted by a command from the remote terminal. Boundary "D" transfers are completed through SUPE5 and SUPE2 while communication across boundary "C" is accomplished by the A/D, D/A and D/D channels associated with the Sigma 2 interface.

Note that SUPE2 in configuration 1 is a subroutine whereas SUPE2 is a main program in operating modes 2 and 3. The software is set up so that versions of SUPE2, EAMCS, TYPCON, FIGSEN and ACTCMD can reside in the Sigma 5 and 2 simultaneously. This permits all three operating configurations to be tested without the necessity of reloading object programs.

4.2 Supervisory Software

Experimental active mirror software control is complicated by the dichotomization of the computer system into two essentially autonomous parts consisting of a large scale general purpose computer,

[*] i.e., subroutine RESPON calls subrouting EAMCS.

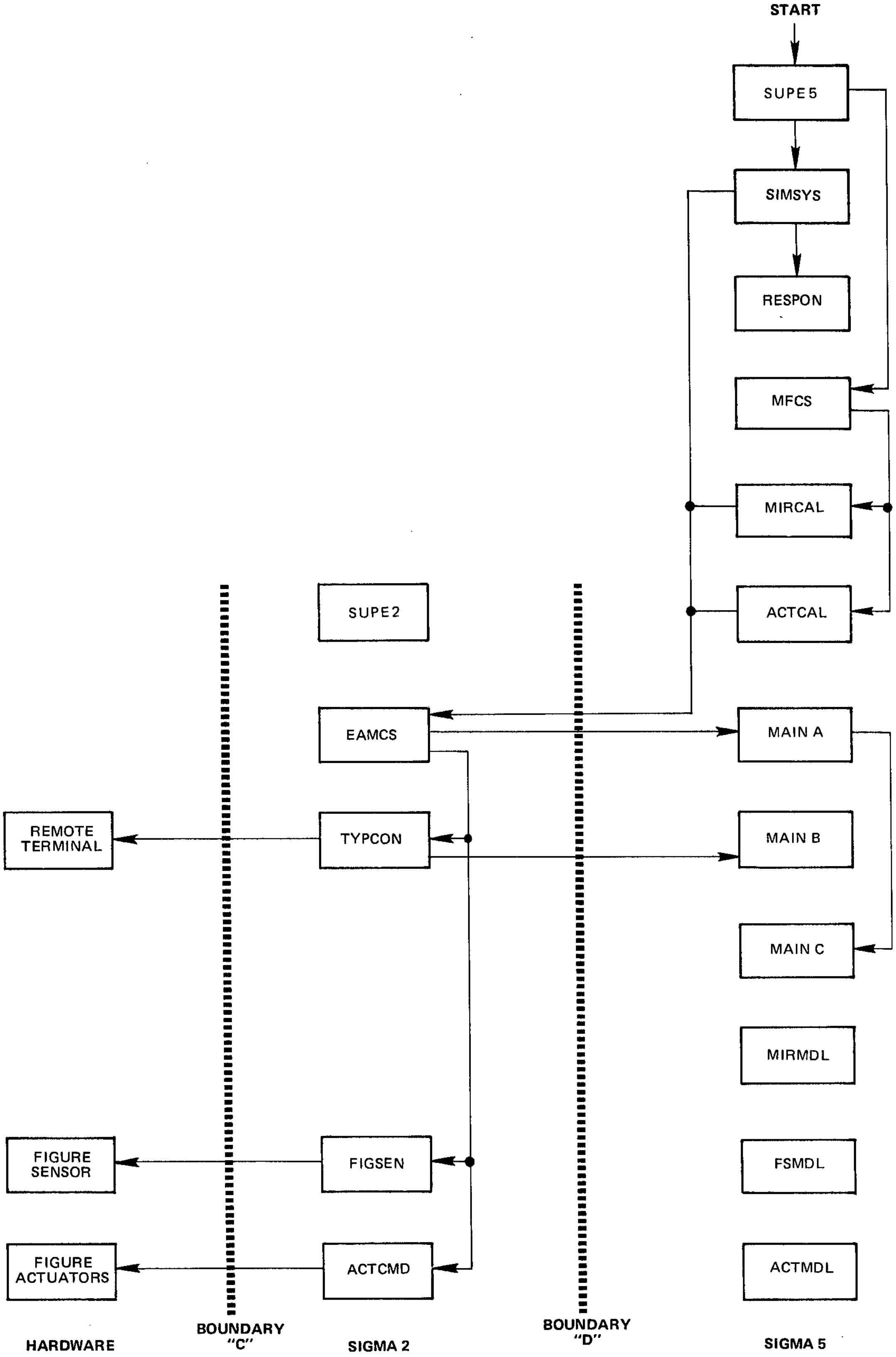


Fig. 4.1.2 Major subrouting calling priorities in the EAM simulation mode.

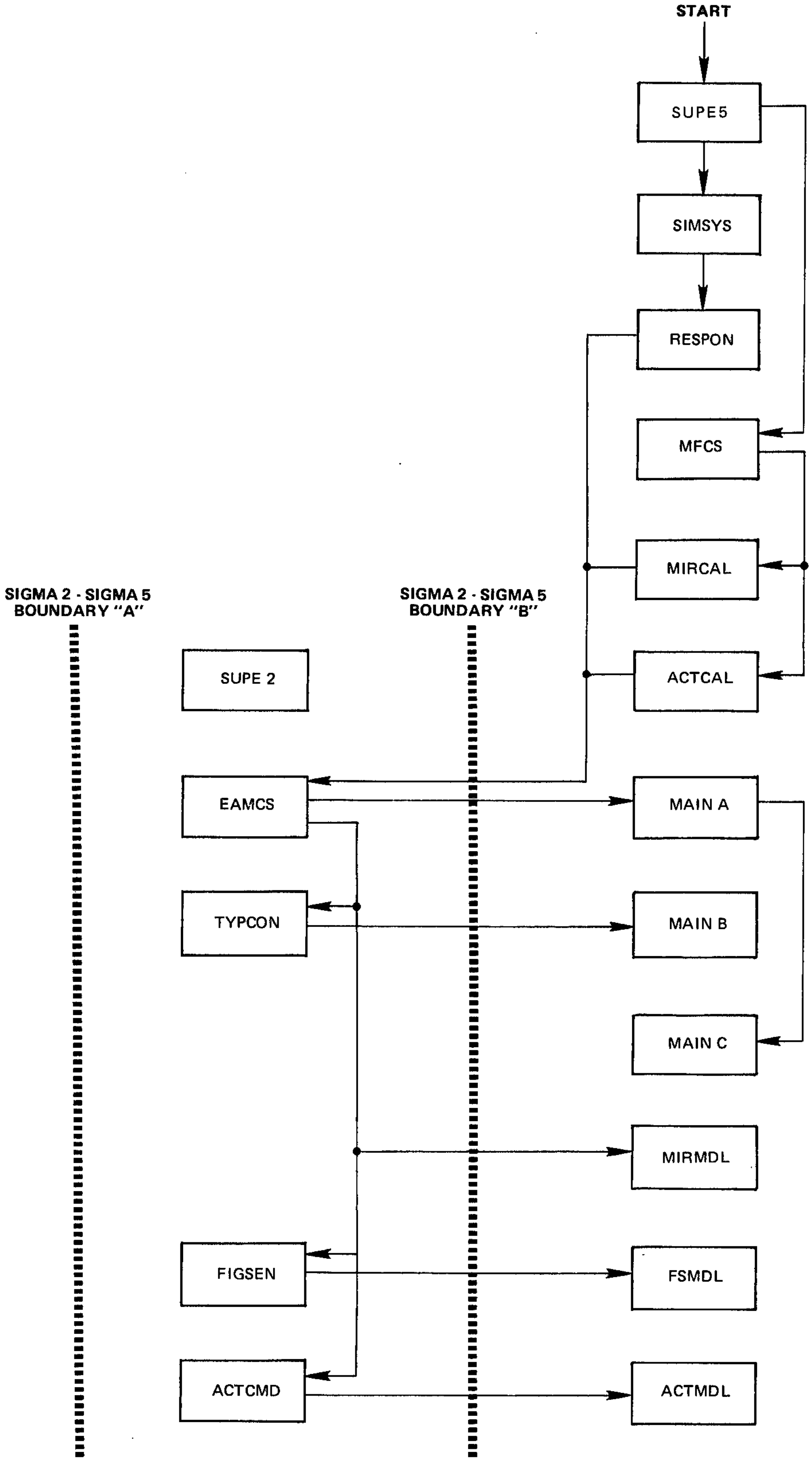


Fig. 4.1.3 Major subroutine calling priorities in the EAM experiment operating mode.

the XDS Sigma 5/7, and a small limited capacity machine, the XDS Sigma 2. Real-time control functions are restricted to the Sigma 2 which plays an essentially dedicated role in the experiment. When computation complexity exceeds the abilities of the Sigma 2, a data processing request is placed for the Sigma 5. Because of the limitations of the current Sigma 5-2 operating system, it was decided to provide the control structure in the form of two programs SUPE5 and SUPE2 which serve as main programs in the Sigma 5 and Sigma 2 respectively.

Transfer of computation responsibility between the computers presents a number of unusual problems. It was decided to treat each computer's software as an essentially independent program. Data communication between the computers is restricted to the transfer of a common data block. Transfers from the Sigma 2 to the Sigma 5 are accomplished by the following sequence of operations.

1. Catalog the destination and return subroutine identification numbers and NENTRY values.
2. Return Sigma 5 program control to SUPE5.
3. Transfer the Sigma 2 subroutine identification number and NENTRY value to the Sigma 2 as part of the common storage block via NFLGA and NFLGB.
4. Transmit an enable signal to the Sigma 2 to initiate execution of the Sigma 2 software. A computed "GO TO" statement in SUPE2 assures transfer to the 2 subroutine with the appropriate value of NENTRY.
5. Terminate computation in the Sigma 5.

The Sigma 2 computer will continue to perform the programmed operations in the selected section of the Sigma 2 software until they are complete. On completion return to the Sigma 5 is achieved by the following sequence.

6. The exit point from the Sigma 2 routine is identified by assigning a value to NFLGA.
7. Sigma 2 program control is returned to SUPE2.
8. SUPE2 enables an interrupt which initiates execution of SUPE5 and terminates Sigma 2 computation.
9. SUPE5 transfers the contents of the common data block from the Sigma 2 to the Sigma 5 memory.
10. SUPE5 uses its addressing structure to determine the return address in the Sigma 5 software.
11. Control is transferred to the identified Sigma 5 subroutine with the appropriate value of NENTRY.

A transfer of computational authority from the Sigma 2 to the Sigma 5 uses the following procedure.

1. The Sigma 2 software exit point is identified by a value of NFLGA.
2. Return Sigma 2 program control to SUPE2.
3. Enable an interrupt requesting execution of SUPE5 in the Sigma 5.
4. Terminate computation in the Sigma 2.

The Sigma 5 monitor will begin execution of SUPE5 as soon as it comes to the head of the job queue.

5. Begin execution of SUPE5.
6. SUPE5 transfers the contents of the common data base from the 2 to the 5.

7. Use the value of NFLGA to establish a new Sigma 5 destination Sigma 2 return address catalogue entry.
8. Extract the address and NENTRY value for the subroutine in the Sigma 5.
9. Transfer to the 5 subroutine to perform the desired computation.
10. Return control to SUPE5.
11. Extract the return address in the Sigma 2 software package.
12. Transmit the common data block to the Sigma 2.
13. Enable an interrupt requesting execution of SUPE2.
14. Terminate Sigma 5 computation.
15. Transfer to the return address in the Sigma 2.

Note that the above procedures permit most of the complex transfer control logic to reside in the Sigma 5, thus minimizing Sigma 2 memory storage requirements.

A readily apparent problem is that of initially starting program execution. This problem is circumvented by using an IF statement to compare the value of a program variable ISTART to 9999 as the first statement in SUPE5. Since the XDS Sigma 5 sets all program storage to zero during loading, the initial value of ISTART is zero. Thus equality is initially violated, and a branch occurs to a section of SUPE5 which performs initialization and sets ISTART = 9999. Thus subsequent entries to SUPE5 will skip the initialization step.

4.3 Cataloging Transfer Data

Each time a transfer is initiated between the Sigma 5 and Sigma 2 or vice versa it is necessary to store the following information:

1. The identification of the subprogram to which transfer is desired.
2. The value of NENTRY which appears in the destination subroutine parameter list when it is called.
3. The identification of the subroutine to which return is desired when the computations in the destination software are complete.
4. The value of NENTRY to be used in the subroutine parameter list when the return address subroutine is called.

In order to facilitate this process the subroutines' names are each associated with a distinct identifying number, as indicated in Table 4.3.1. Each time a transfer is initiated numbers corresponding to 1, 2, 3 and 4 above are stored by inserting them as parameters in subroutine MARK which is then called with NENTRY = 1. For example:

CALL MARK (1, 24, 4, 4, 3) (4.3.1)

indicates that a catalog entry is to be generated. A transfer to subroutine TYPCON (4) is desired. When the operations designated in TYPCON (4) are complete, MAINB (3) should be called. Instruction (4.3.1) stores the address information and identifies the new catalog entry by incrementing an integer ITRANS which is equal to the number of entries which have been generated.

The latest address data may be extracted from the catalog by calling MARK with NENTRY = 2 or 3. The instruction:

CALL MARK (2, NFLGA, NFLGB, IA, IA) (4.3.2) sets NFLGA, NFLGB equal to the destination subroutine identification number and NENTRY value respectively. The return address is produced by the call:

CALL MARK (3, IA, IA, NFLGA, NFLGB) (4.3.3)

which also deletes the present address data by decrementing ITRANS.

Table 4.3.1

SUBROUTINE	SIGMA 5 IDENTIFICATION NUMBER (NFLGA)	SIGMA 2 IDENTIFICATION NUMBER (NFLGA)
SIMSYS	1	
MFCS	2	
MAINA	3	
MAINB	4	
FSMDL	5	
MIRMDL	6	
RESPON	7	
ACTCAL	8	
MIRCAL	9	
ACTMDL	10	
ACTCMD	21	1
EAMCS	22	2
FIGSEN	23	3
TYPCON	24	4

4.4 Determination of the Transfer Address

The addressing structure of SUPE5 provides the subroutine identification number NFLGA and the entry point NFLGB for each Sigma 5 - 2 or 2 - 5 transfer. Since SUPE5 directly controls transfers to any desired subroutine and entry point, it is necessary to provide some method of indicating whether or not the transfer is to a destination or a return address. This is accomplished by counting the number of catalog entries. The number of destination - return addresses is stored in ITRANS which is incremented every time a new catalog entry is generated. The value of ITRANS at the completion of the last use of the addressing structure is stored in ISTORE. ITRANS is compared with ISTORE at the beginning of the addressing structure. If ITRANS is greater than ISTORE, the current catalog entry is new and a destination address is generated by calling MARK with NENTRY = 2. If on the other hand, ITRANS equals ISTORE a return address is desired and MARK is called with NENTRY = 3. A request for a return address signifies the completion of a cataloged Sigma 2 - 5 or 5 - 2 transfer and automatically deletes the current catalog entry by decrementing ITRANS.

4.5 Experimental Active Mirror Simulation

Simulation of the experimental active mirror is accomplished by combining a simulation control structure (RESPON) with the actual mirror control software (ACTCMD, EAMCS, FIGSEN, and TYPCON) and software models of the hardware components (ACTMDL, FSMDL, MIRMDL).

A block diagram of the simulation is shown in Fig. 4.5.1. The control system is operated for one cycle by calling EAMCS with NENTRY = 4 and NTIMSQ = 1.

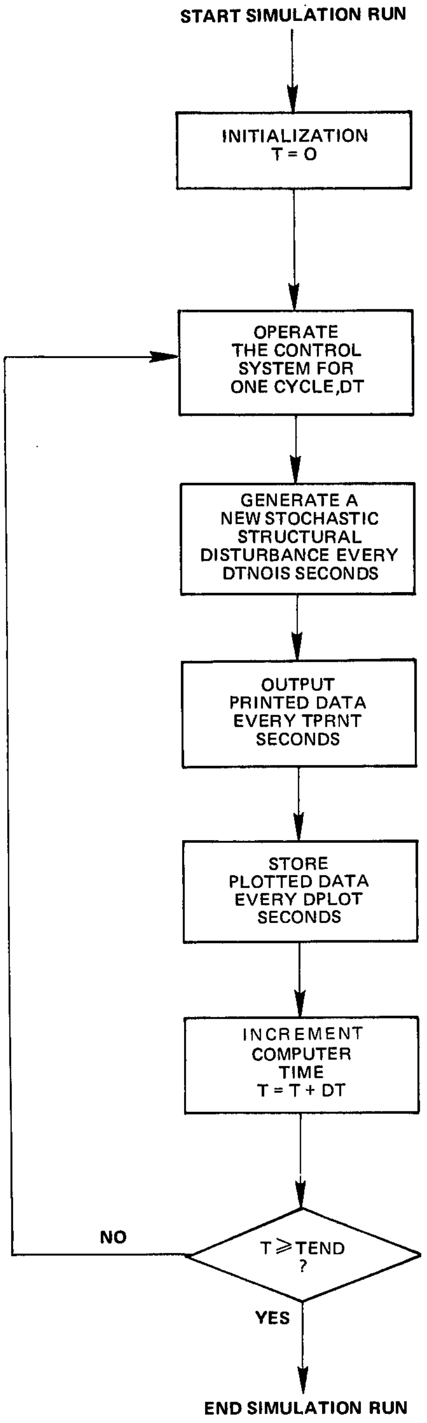


Fig. 4.5.1 Simplified block diagram of the EAM simulation.

Provision is made for the inclusion of a stochastic structural disturbance generator to simulate the effect of random orbital disturbances. A new random disturbance is requested every DTNOIS seconds.

The simulation is designed to output data every TPRNT seconds on the Sigma 5 line printer. The data illustrated in Fig. 4.5.2 includes the time, T, the performance index, PINDEX, actual figure error, XFAV, sensed figure error, XFV, commanded figure control, UFV, and the actual figure control, UFAV. Diagnostic information, useful for figure control system development, is also provided.

Data for online or offline plotting is processed and stored every DTPLOT seconds by subroutines PLRT and STORED.

The simulation run is terminated when the simulation time exceeds the input limit TEND. On termination program control is returned to SIMSYS.

4.6 Experimental Active Mirror Experiment Operation

Operation of the experiment is achieved by selecting the appropriate operating mode configuration using the mode descriptions in section 5.2.2. The OPERATE CONTROL SYSTEM, USE HARDWARE COMPONENTS and SIGMA 5 - 2 CONFIGURATION modes must be selected. Once all input has been read, TYPCON will request instructions from the remote control terminal for initializing and starting the experiment. A detailed description of the remote control functions is contained in Chapter 6. Once operation is achieved, the hardware components function under the control of EAMCS which realizes the control sequence illustrated in Fig. 3.4.2.

```
          T=      19.499588        PINDEX=        .048106
       XFAV
    .063274        .056394        .071686        .063274        .056394        .071686        .063274
    .056394        .071686        .024251        .024251        .024251        .024251        .024252
    .024252        .072268
        XFV
   -.010830       -.081613       -.030304       -.010830       -.081613       -.030304       -.010830
   -.081613       -.030304       -.047116       -.047116       -.047116       -.047116       -.047116
   -.047116       -.024883
        UFV
    .026524       -.014526        .026524       -.014526        .026524       -.014526       -.024413
       UFAV
    .026524       -.014526        .026524       -.014526        .026524       -.014526       -.024413
       XFMN          XFSIG          AMBIG         XFMEAS           XFSW         XFLAST          LSENS
   -.081613        .000000        .000000       -.081613       -.250000       -.081613       2.000000
      JMEAS          JWAIT          JSENS          ISENS          XFACT         PINDEX          FSØUT
   1.000000       2.000000       2.000000       5.000000        .000000        .048106        .024251
      FSERR       FSPINDEX    FSNØIS SIG         FSNØIS        RPINDEX
    .000000        .000000        .000000        .000000        .048106
```

Fig. 4.5.2   Typical simulation output print.

A simplified flow diagram of EAMCS is shown in Fig. 4.6.1. The major part of EAMCS is associated with the acquisition of figure error data. The collected measurements are processed by the Sigma 5 to eliminate measurement ambiguities and to produce a new figure control. The remaining portion of EAMCS operates the actuator control systems, controls the real-time control cycle duration, and provides an experiment interrupt provision which enables the operator to suspend operation for diagnostic or other purposes via the remote terminal. The experiment is automatically terminated when NTIMSQ* control cycles have elapsed.

4.7 EAM Software Descriptions and Functional Block Diagrams

The following subsections contain brief descriptions and functional block diagrams of the major components of the EAM software. The program descriptions and functional block diagrams are arranged in alphabetical order.

4.7.1 ACTCAL: Actuator Calibration

ACTCAL provides the software necessary to check the figure actuators for correct operation. The software perturbs each element of the actuator command vector m_{ci} by $\pm \delta_{aa}$ and observes the corresponding change in the measured output m_{mi}. The command perturbation - output measurement sequence is repeated n_{ma} times. The average ratio between the output and input perturbations is then calculated using the relationship:

$$\frac{\delta m_{mi}}{\delta m_{ci}} = \frac{1}{n_{ma}} \sum_{j=1}^{n_{ma}} \frac{1}{2\delta_{aa}} \left[\left(m_{mi}\right)_{m_{ci} = \delta_{aa}} - \left(m_{mi}\right)_{m_{ci} = -\delta_{aa}} \right]_j \tag{4.7.1}$$

* NTIMSQ = NTIMS

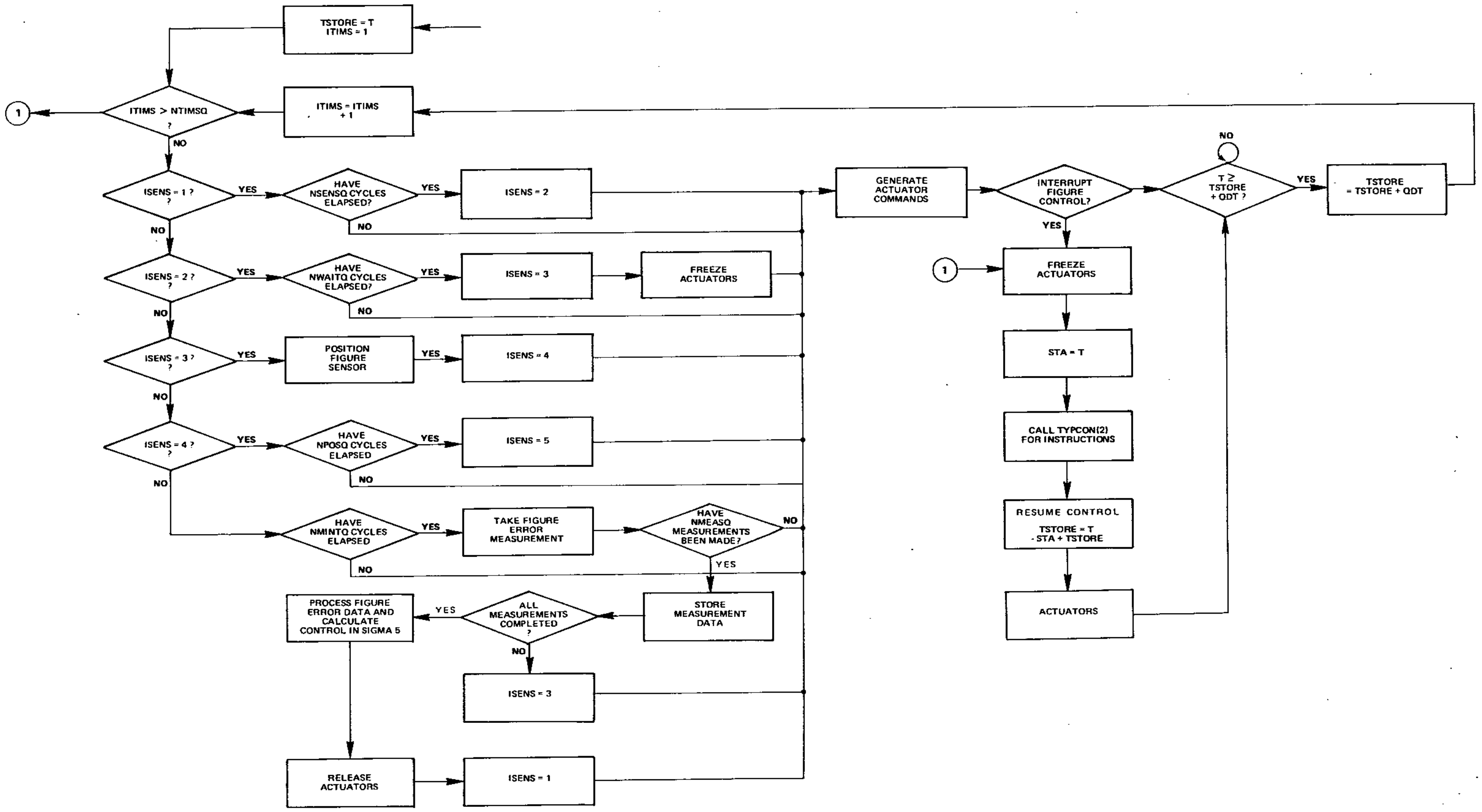

TSTORE = T
ITIMS = 1
ITIMS = ITIMS + 1
ITIMS > NTIMSQ ?
1
NO
ISENS = 1 ? ?
YES
HAVE NSENSQ CYCLES ELAPSED?
YES
NO
ISENS = 2
ISENS = 2 ? ?
HAVE NWAITQ CYCLES ELAPSED?
ISENS = 3
FREEZE ACTUATORS
ISENS = 3 ? ?
POSITION FIGURE SENSOR
ISENS = 4
ISENS = 4 ? ?
HAVE NPOSQ CYCLES ELAPSED
ISENS = 5
HAVE NMINTQ CYCLES ELAPSED
TAKE FIGURE ERROR MEASUREMENT
HAVE NMEASQ MEASUREMENTS BEEN MADE?
STORE MEASUREMENT DATA
ALL MEASUREMENTS COMPLETED ?
PROCESS FIGURE ERROR DATA AND CALCULATE CONTROL IN SIGMA 5
ISENS = 3
RELEASE ACTUATORS
ISENS = 1
GENERATE ACTUATOR COMMANDS
INTERRUPT FIGURE CONTROL?
T ≥ TSTORE + QDT ?
TSTORE = TSTORE + QDT
FREEZE ACTUATORS
STA = T
CALL TYPCON(2) FOR INSTRUCTIONS
RESUME CONTROL
TSTORE = T - STA + TSTORE
ACTUATORS

Fig. 4.6.1 Simplified flow diagram of EAMCS.

The actuator output command perturbations and output measurements are executed by EAMCS via ACTCMD. A flow diagram of ACTCAL is shown in Fig. 4.7.1.

4.7.2 ACTCMD: Figure Actuator Control Systems

ACTCMD provides the necessary closed loop control for the mirror figure actuators. ACTCMD also transfers the actuator commands to the actuator models and returns the actuator model outputs in the EAM simulation mode. Provisions are also made to freeze the actuator positions whenever computational authority is transferred to the Sigma 5. A detailed discussion of the actuator control algorithms is given in sections 3.6 and 3.7. Figure 4.7.2 shows a flow diagram of ACTCMD.

4.7.3 ACTMDL: Mirror Figure Actuator Models

ACTMDL provides software models for the force and position figure actuators. ACTMDL must be called for each figure actuator which is identified in the parameter list by the index IENTRY. A detailed description of the actuator models is given in section 2.9. A flow diagram of ACTMDL appears in Fig. 4.7.3.

4.7.4 EAMCS: Hardware Component Control Software

The Sigma 2 subroutine EAMCS provides the core of the real-time figure control system. In this routine the physical characteristics of the hardware components are considered. The primary functions of EAMCS are to provide: an actuator control time interval during which the actuators can reach a steady state; actuator freeze signals to inhibit actuator motion during figure error measurement and data processing; position commands to the figure sensor image dissector; figure sensor data acquisition and storage; and actuator control system commands. Further discussion of the real-time control system is given in sections 3.4., 4.6 and Chapter 5. A flow diagram of EAMCS is given in Fig. 4.7.4.

4.7.5 FIGSEN: Figure Sensor Control Module

Subroutine FIGSEN provides the communications link between the EAM software and the mirror figure sensor. FIGSEN transfers position commands to the image dissector and interrogates the output of the figure sensor phase detector fitter. In the simulation mode FIGSEN obtains figure sensor output data from the figure sensor model FSMDL. Figure 4.7.5 shows a flow diagram of FIGSEN.

4.7.6 FSMDL: Figure Sensor Model

FSMDL provides a software model of the figure sensor. FSMDL also provides software for reading the figure sensor model data, calculating performance indices, and constructing the plot data transfer vector XV. A flow diagram of FSMDL is presented in Fig. 4.7.6.

4.7.7 MAINA: EAM System Computations

MAINA inputs all the sequence timing data for the digital control system. MAINA also reads in the gains for the figure and actuator control algorithms, the saturation limit m_{max} on the actuator commands and the figure sensor data processing algorithm parameter values. MAINA provides calls to the EAM component models and performance index generator data input. In the initialization mode MAINA provides coding and/or subroutine calls to initialize the entire EAM system. During EAM operation or simulation MAINA provides software for figure sensor data processing and actuator command computation. A flow diagram of MAINA appears in Fig. 4.7.7.

4.7.8 MAINB: Remote Control Operations

MAINB provides service operations on EAM program variables for the remote terminal. The service operations include the interpretation of an input variable identification, variable display, and variable modification. MAINB also provides computations required to process data for display on the remote terminal during experiment operation. A flow diagram of MAINB is shown in Fig. 4.7.8.

4.7.9 MAINC: Initial Alignment Computations

MAINC provides coding for the mirror segment tilt and axial alignment control systems. MAINC reads in all the required data and provides coding for the segment actuator command computations using figure and ambiguity sensor data. A flow diagram of MAINC is shown in Fig. 4.7.9.

4.7.10 MFCS: Control System Data Input and Gain Matrix Computation

Subroutine MFCS reads all the basic information for the experimental active mirror control system and simulation. If MODOP = 1 or 2 MFCS computes the simplified linear or linear optimal feedback gain matrix respectively. A value of MODOP = 3 results in the input of a general n_r by n gain matrix as part of the input data deck. MFCS also provides calls to ACTCAL and MIRCAL for actuator and mirror tests. Figure 4.7.10 shows a flow diagram of MFCS.

4.7.11 MIRCAL: Mirror Calibration

Subroutine MIRCAL provides the software required to experimentally evaluate the reduced deformation-force matrix A_r of the mirror which relates deformations at selected points on the mirror surface to perturbations δ_{af} in the actuator outputs. The reduced matrix is measured n_{mf} times and the results averaged. The relationship between the deformation at the ith measurement point x_{fmi} due to a change in the jth actuator output m_{cj} is:

$$a_{ij} \approx \frac{1}{n_{mf}} \sum_{k=1}^{n_{mf}} \frac{1}{2\delta_{af}} \left[\left(x_{fmi}\right)_{m_{ci} = \delta_{af}} - \left(x_{fmi}\right)_{m_{ci} = -\delta_{af}} \right]_k \qquad (4.7.2)$$

The resulting matrix is displayed on the Sigma 5 line printer. MIRCAL is shown in flow diagram form in Fig. 4.7.11.

4.7.12 MIRMDL: Mirror Model

MIRMDL provides a linear representation of the deformable or segmented mirror for use in the EAM simulation. The equation of the mirror model has the form:

$$x_f = x_d + A_r m_m \qquad (4.7.3)$$

where x_f is the figure error; x_d the initial figure disturbance; A_r the reduced position-position or deformation-force matrix and m_m the position or force actuator outputs. A flow diagram of MIRCAL appears in Fig. 4.7.12.

4.7.13 PINDX: Performance Index Generator

The subroutine PINDX accepts the n dimensional array x and returns a performance index evaluated using the equation:

$$J = \left[\sum_{i=1}^{n} w_i x_i^2 \right]^{1/2} \qquad (4.7.4)$$

where w is an input array of positive weights and x is a parameter array. For an unbiased index $w_i = n^{-1}$ i = 1, n. Figure 4.7.13 shows a flow diagram of PINDX.

4.7.14 PLRT: Plotted Data Storage and Scaling

Subroutine PLRT provides the software required to store, scale and plot simulation data. Potential data for plotting must be stored in XV. The NPLOTV elements of XV to be stored every DTPLOT seconds are identified by the elements of IPLOTV. The scales to be used when each element is plotted are stored in the array SCALV. MODV contains elements which indicate whether or not the corresponding element of XV is to be plotted using the input scale factor or a scale factor produced automatically. If IMODV (I) is 2, a scale factor is automatically generated for the data corresponding to XV (IPLOTV (I)). Automatic scale factor generation is omitted if IMODV (I) = 1. A flow diagram of PLRT is delineated in Fig. 4.7.14.

4.7.15 RESPON: Simulation Control Software

Subroutine RESPON provides the control structure for the EAM Simulation. RESPON initializes the EAM models and control software and the simulation data collection and processing programs. During simulation RESPON provides calls to EAMCS every control cycle, artificial real-time generation, stochastic structural disturbance inputs, as well as outputs for the line printer and the data plotting routine. See Fig. 4.7.15 for a flow diagram of RESPON.

4.7.16 SIMSYS: Program Control Module

SIMSYS provides the computations and/or calls required required to read in all EAM system data. Provisions are also included to permit a number of simulation runs to be performed automatically, each with data modifications provided by a data editing capability. Thus it is possible to make up to ten simulation runs with different values of β_g for example without the necessity of reloading the data deck. In the hardware operating mode SIMSYS allows the experiment to select any of the possible edited data configurations via remote terminal commands. SIMSYS is flow charted in Fig. 4.7.16.

4.7.17 STORED: Plotting Control Software

Subroutine STORED provides the coding required to plot the data prepared by PLRT using Calcomp plotting routines. Figure 4.7.17 shows a flow chart of STORED.

4.7.18 SUPE2: Main Sigma 2 Program

SUPE2 is the main program resident in the Sigma 2. SUPE2 provides a computed transfer to the Sigma 2 subroutine identified by the value of NFLGA.

4.7.19 SUPE5: Main Sigma 5 Program

The main program in the Sigma 5 provides the software required to store Sigma 2 transfer data; to extract subroutine address data from the transfer file and to transfer to subroutines in the Sigma 5. Refer to Fig. 4.7.19 for a functional block diagram of SUPE5.

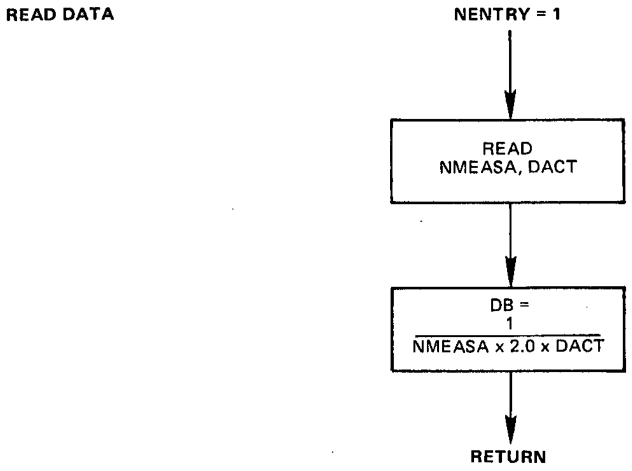


Fig. 4.7.1 ACTCAL flow diagram.

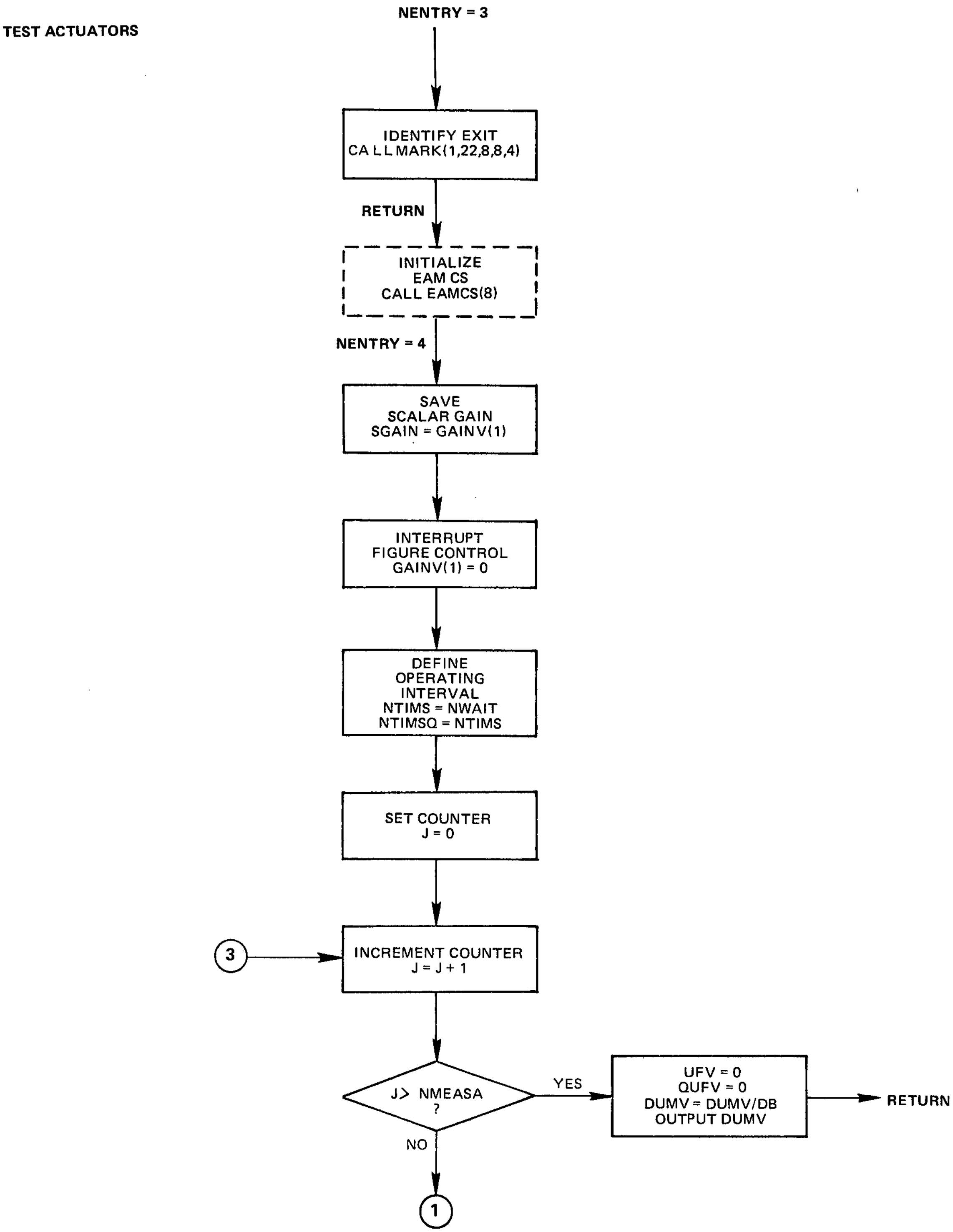

TEST ACTUATORS
NENTRY = 3
IDENTIFY EXIT
CA LL MARK(1,22,8,8,4)
RETURN
INITIALIZE
EAM CS
CALL EAMCS(8)
NENTRY = 4
SAVE
SCALAR GAIN
SGAIN = GAINV(1)
INTERRUPT
FIGURE CONTROL
GAINV(1) = 0
DEFINE
OPERATING
INTERVAL
NTIMS = NWAIT
NTIMSQ = NTIMS
SET COUNTER
J = 0
3
INCREMENT COUNTER
J = J + 1
J> NMEASA
?
YES
UFV = 0
QUFV = 0
DUMV = DUMV/DB
OUTPUT DUMV
RETURN
NO
1

Fig. 4.7.1 Cont.

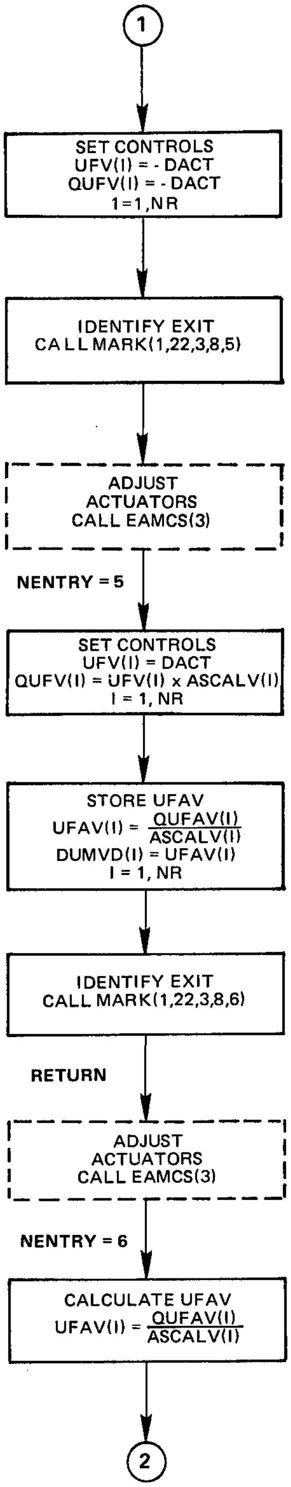

1
SET CONTROLS
UFV(I) = - DACT
QUFV(I) = - DACT
1=1,NR
IDENTIFY EXIT
CALL MARK(1,22,3,8,5)
ADJUST
ACTUATORS
CALL EAMCS(3)
NENTRY = 5
SET CONTROLS
UFV(I) = DACT
QUFV(I) = UFV(I) x ASCALV(I)
I = 1, NR
STORE UFAV
UFAV(I) = QUFAV(I)/ASCALV(I)
DUMVD(I) = UFAV(I)
I = 1, NR
IDENTIFY EXIT
CALL MARK(1,22,3,8,6)
RETURN
ADJUST
ACTUATORS
CALL EAMCS(3)
NENTRY = 6
CALCULATE UFAV
UFAV(I) = QUFAV(I)/ASCALV(I)
2

Fig. 4.7.1 Cont.

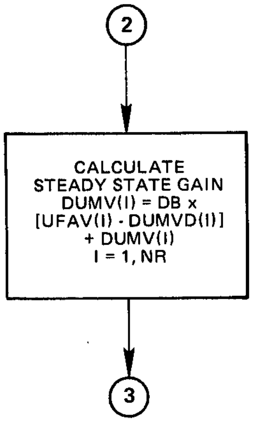

2
CALCULATE
STEADY STATE GAIN
DUMV(I) = DB x
[UFAV(I) - DUMVD(I)]
+ DUMV(I)
I = 1, NR
3

Fig. 4.7.1 Cont.

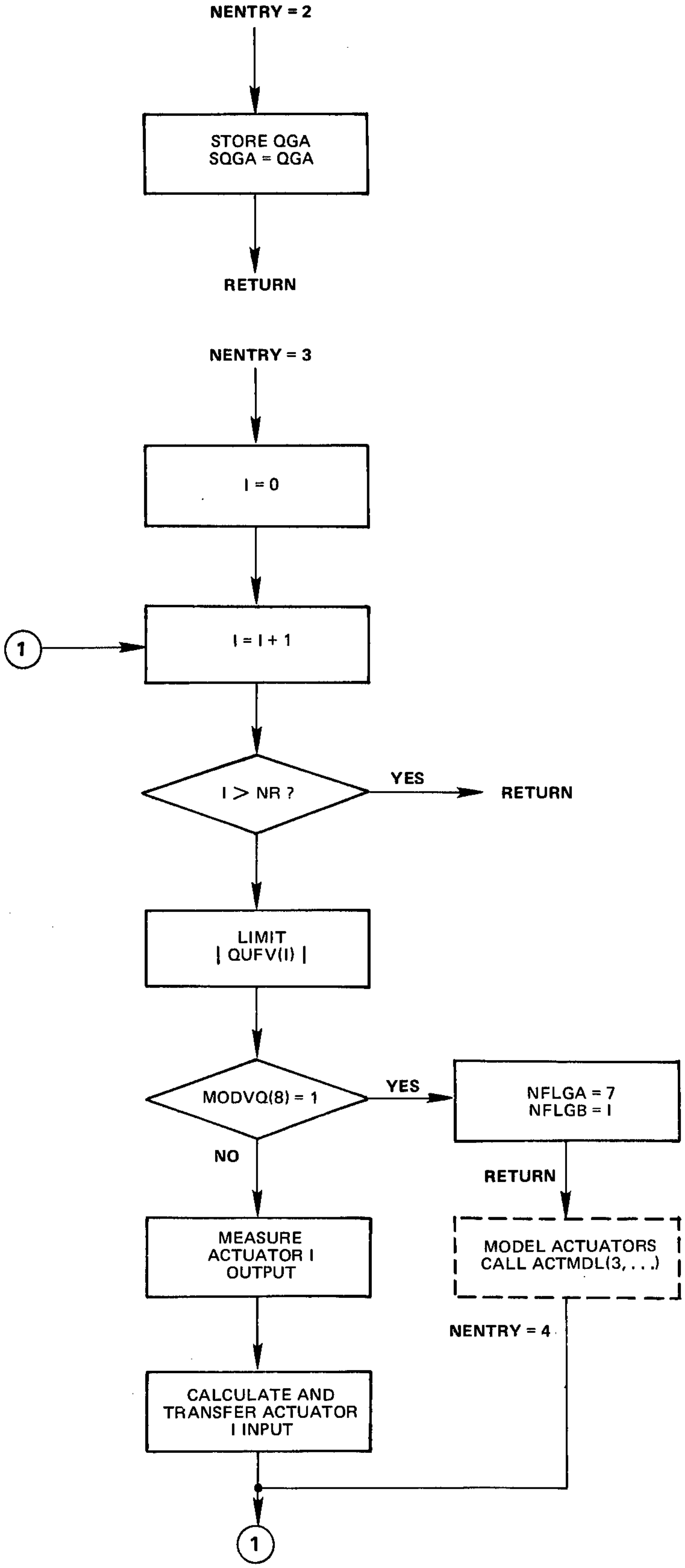


Fig. 4.7.2 ACTCMD flow diagram.

ACTCMD 2/2

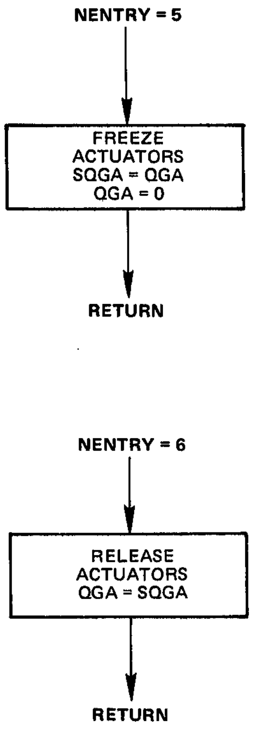

NENTRY = 5
FREEZE ACTUATORS SQGA = QGA QGA = 0
RETURN
NENTRY = 6
RELEASE ACTUATORS QGA = SQGA
RETURN

Fig. 4.7.2 Cont.

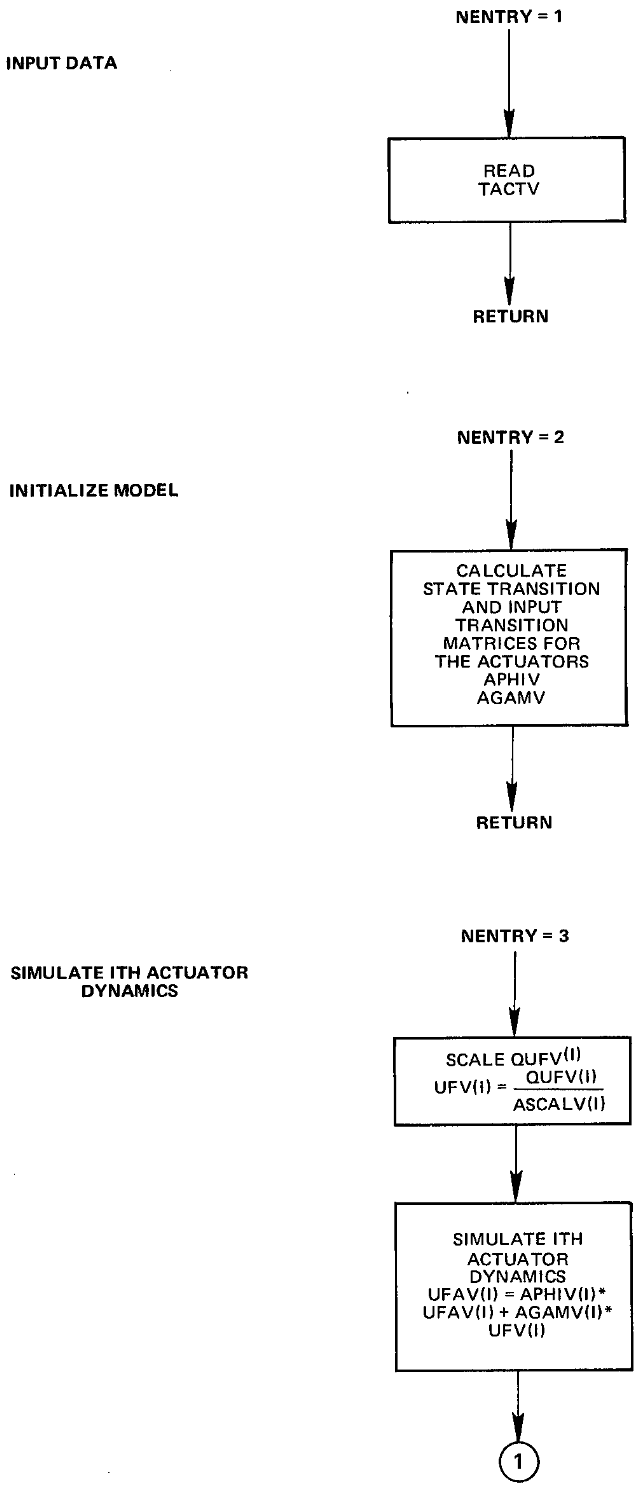

NENTRY = 1
INPUT DATA
READ TACTV
RETURN
NENTRY = 2
INITIALIZE MODEL
CALCULATE STATE TRANSITION AND INPUT TRANSITION MATRICES FOR THE ACTUATORS APHIV AGAMV
RETURN
NENTRY = 3
SIMULATE ITH ACTUATOR DYNAMICS
SCALE QUFV(I)
UFV(I) = QUFV(I) / ASCALV(I)
SIMULATE ITH ACTUATOR DYNAMICS UFAV(I) = APHIV(I)* UFAV(I) + AGAMV(I)* UFV(I)
1

Fig. 4.7.3 ACTMDL flow diagram.

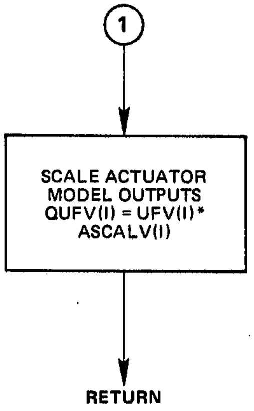


Fig. 4.7.3 Cont.

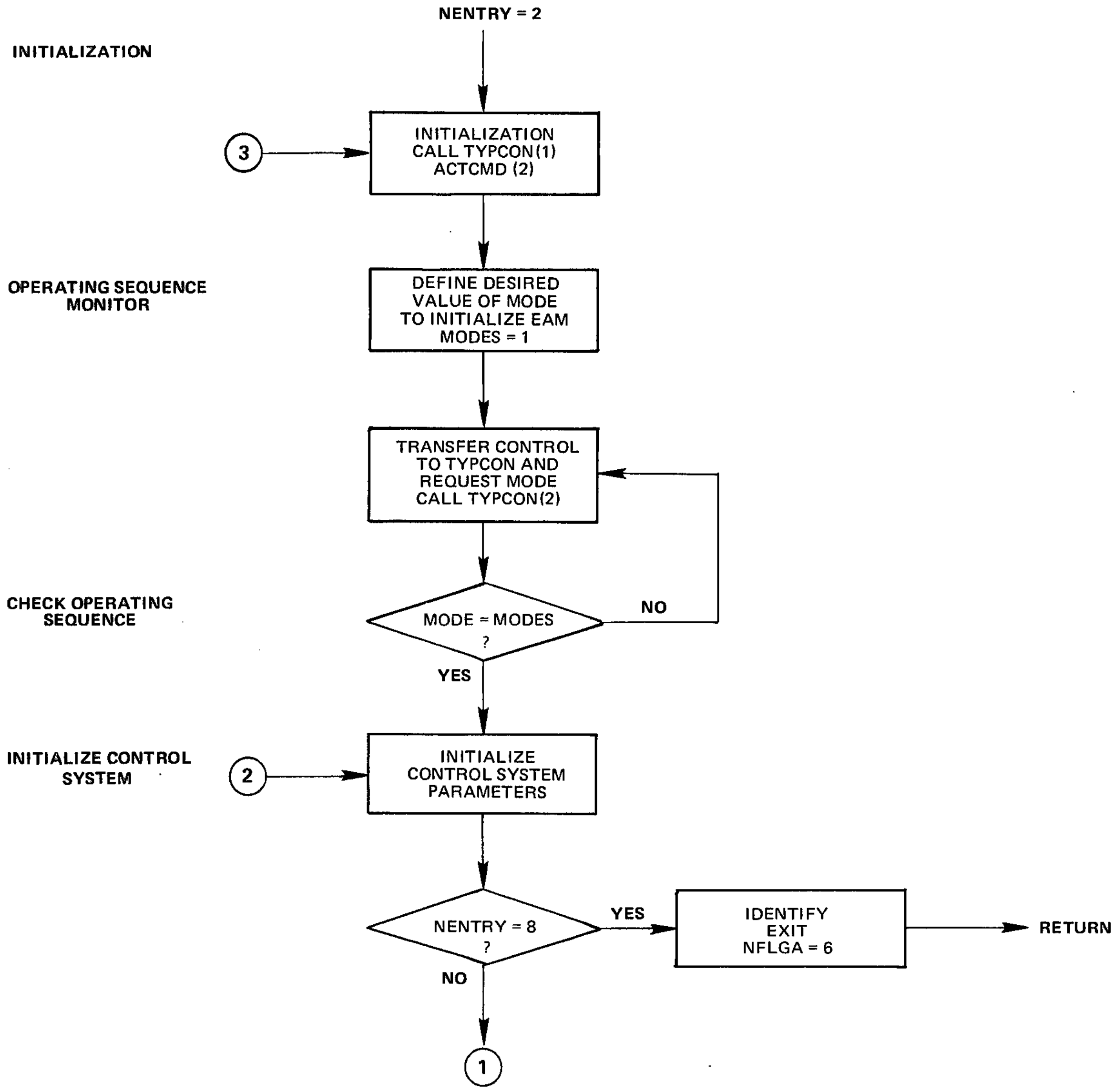

NENTRY = 2
INITIALIZATION
3
INITIALIZATION CALL TYPCON(1) ACTCMD (2)
OPERATING SEQUENCE MONITOR
DEFINE DESIRED VALUE OF MODE TO INITIALIZE EAM MODES = 1
TRANSFER CONTROL TO TYPCON AND REQUEST MODE CALL TYPCON(2)
CHECK OPERATING SEQUENCE
MODE = MODES ?
NO
YES
INITIALIZE CONTROL SYSTEM
2
INITIALIZE CONTROL SYSTEM PARAMETERS
NENTRY = 8 ?
YES
IDENTIFY EXIT NFLGA = 6
RETURN
NO
1

Fig. 4.7.4 EAMCS flow diagram.

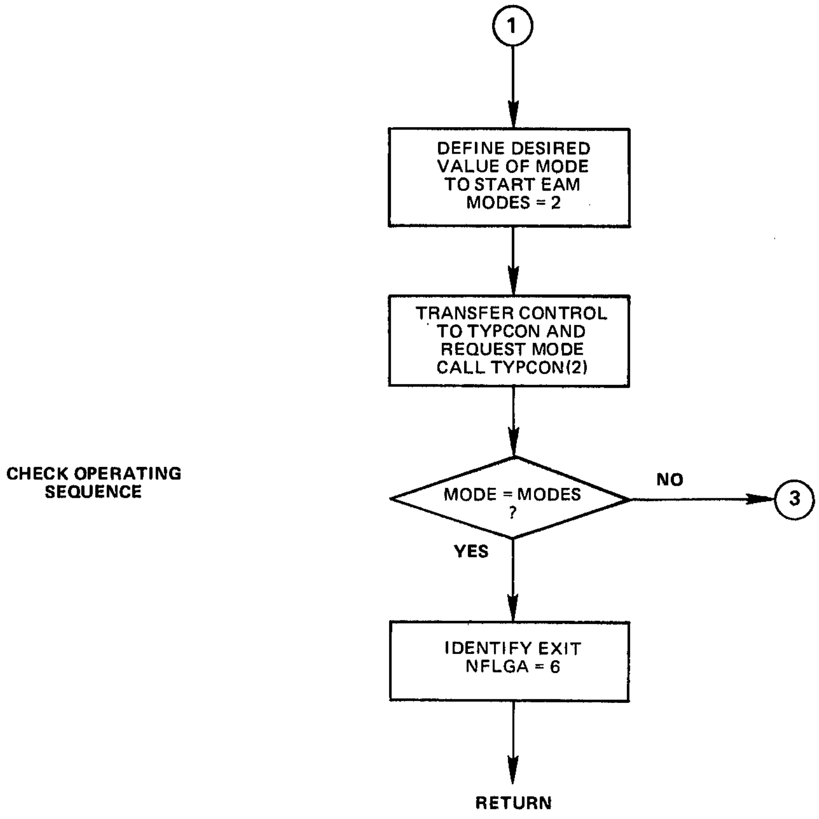

1
DEFINE DESIRED VALUE OF MODE TO START EAM MODES = 2
TRANSFER CONTROL TO TYPCON AND REQUEST MODE CALL TYPCON(2)
CHECK OPERATING SEQUENCE
MODE = MODES ?
NO
3
YES
IDENTIFY EXIT NFLGA = 6
RETURN

Fig. 4.7.4 Cont.

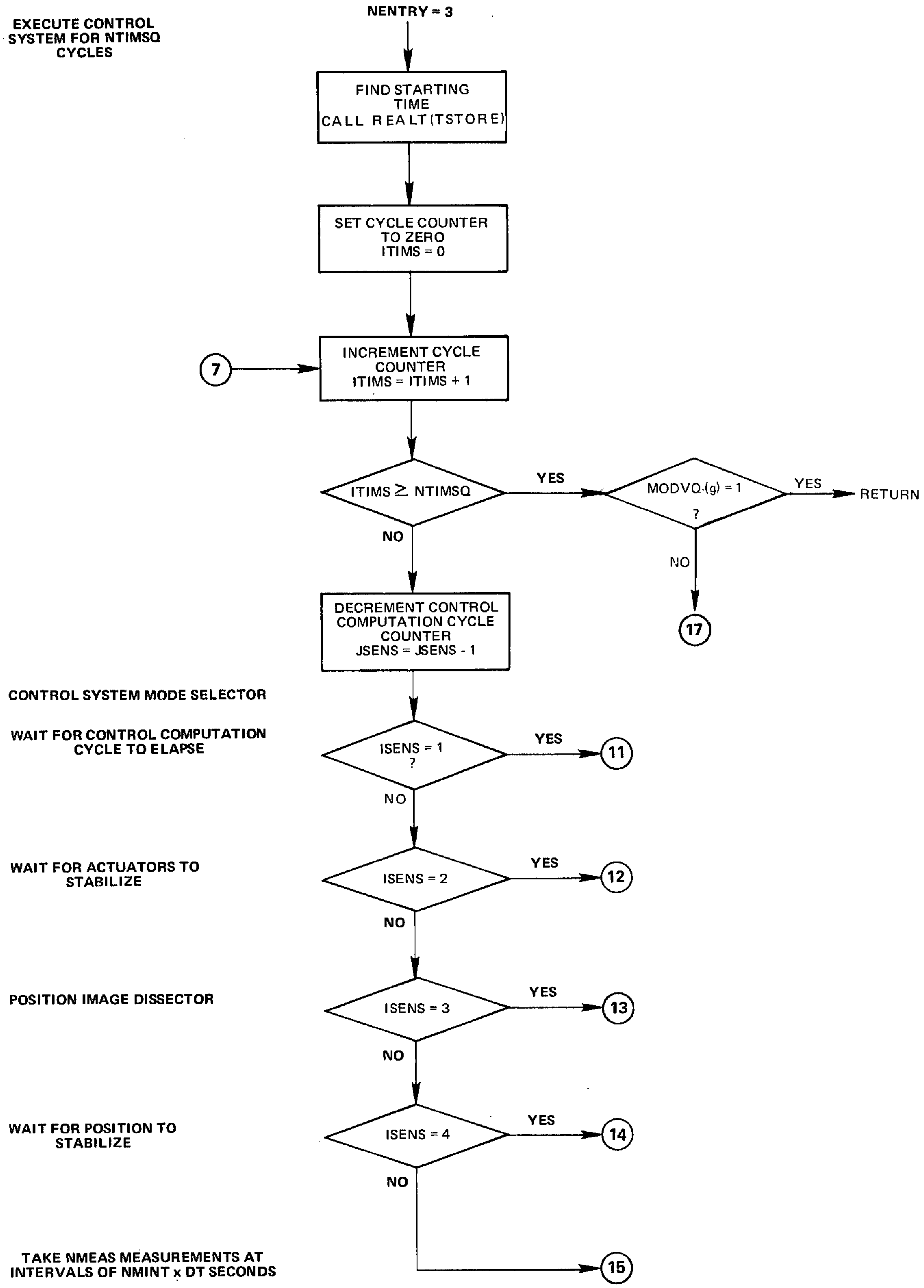
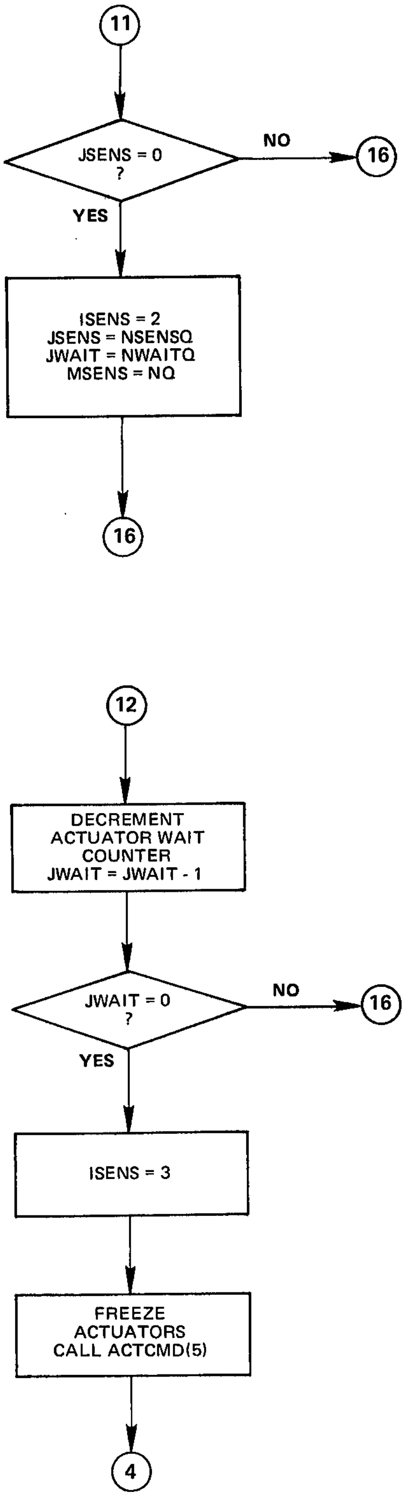

NENTRY = 3
EXECUTE CONTROL SYSTEM FOR NTIMSQ CYCLES
FIND STARTING TIME CALL REALT(TSTORE)
SET CYCLE COUNTER TO ZERO ITIMS = 0
7
INCREMENT CYCLE COUNTER ITIMS = ITIMS + 1
ITIMS ≥ NTIMSQ
YES
MODVQ(g) = 1 ?
YES
RETURN
NO
17
NO
DECREMENT CONTROL COMPUTATION CYCLE COUNTER JSENS = JSENS - 1
CONTROL SYSTEM MODE SELECTOR
WAIT FOR CONTROL COMPUTATION CYCLE TO ELAPSE
ISENS = 1 ?
YES
11
NO
WAIT FOR ACTUATORS TO STABILIZE
ISENS = 2
YES
12
NO
POSITION IMAGE DISSECTOR
ISENS = 3
YES
13
NO
WAIT FOR POSITION TO STABILIZE
ISENS = 4
YES
14
NO
TAKE NMEAS MEASUREMENTS AT INTERVALS OF NMINT x DT SECONDS
15

Fig. 4.7.4 Cont.



WAIT FOR CONTROL COMPUTATION CYCLE TO ELAPSE

WAIT NWAIT CYCLES FOR ACTUATORS TO STABILIZE

Fig. 4.7.4 Cont.

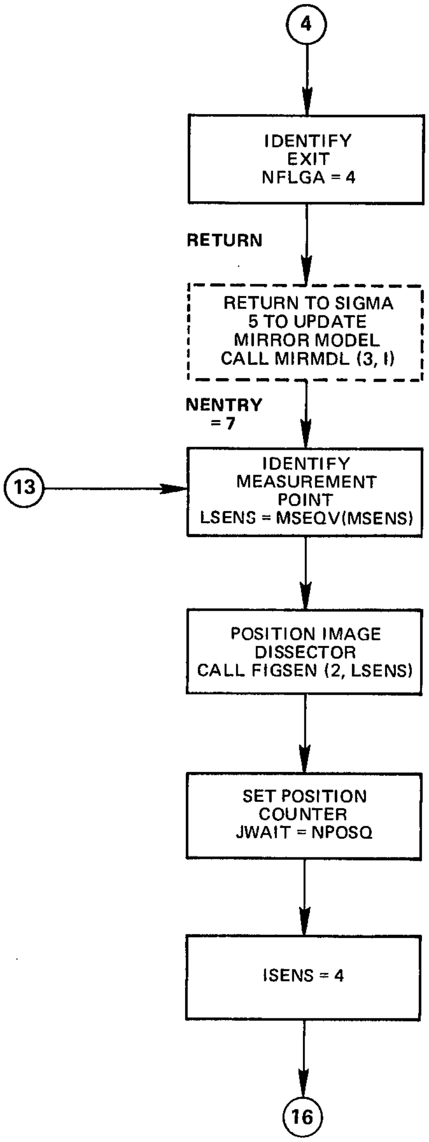

4
IDENTIFY EXIT NFLGA = 4
RETURN
RETURN TO SIGMA 5 TO UPDATE MIRROR MODEL CALL MIRMDL (3, I)
NENTRY = 7
13
IDENTIFY MEASUREMENT POINT LSENS = MSEQV(MSENS)
POSITION IMAGE DISSECTOR CALL FIGSEN (2, LSENS)
SET POSITION COUNTER JWAIT = NPOSQ
ISENS = 4
16

Fig. 4.7.4 Cont.

WAIT FOR MEASUREMENT POSITION TO STABILIZE

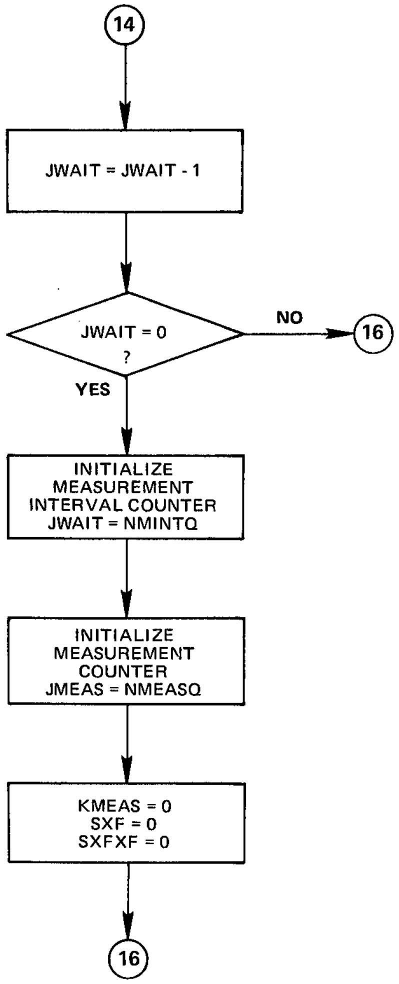

14
JWAIT = JWAIT - 1
JWAIT = 0 ?
NO
16
YES
INITIALIZE MEASUREMENT INTERVAL COUNTER JWAIT = NMINTQ
INITIALIZE MEASUREMENT COUNTER JMEAS = NMEASQ
KMEAS = 0
SXF = 0
SXFXF = 0
16

Fig. 4.7.4 Cont.

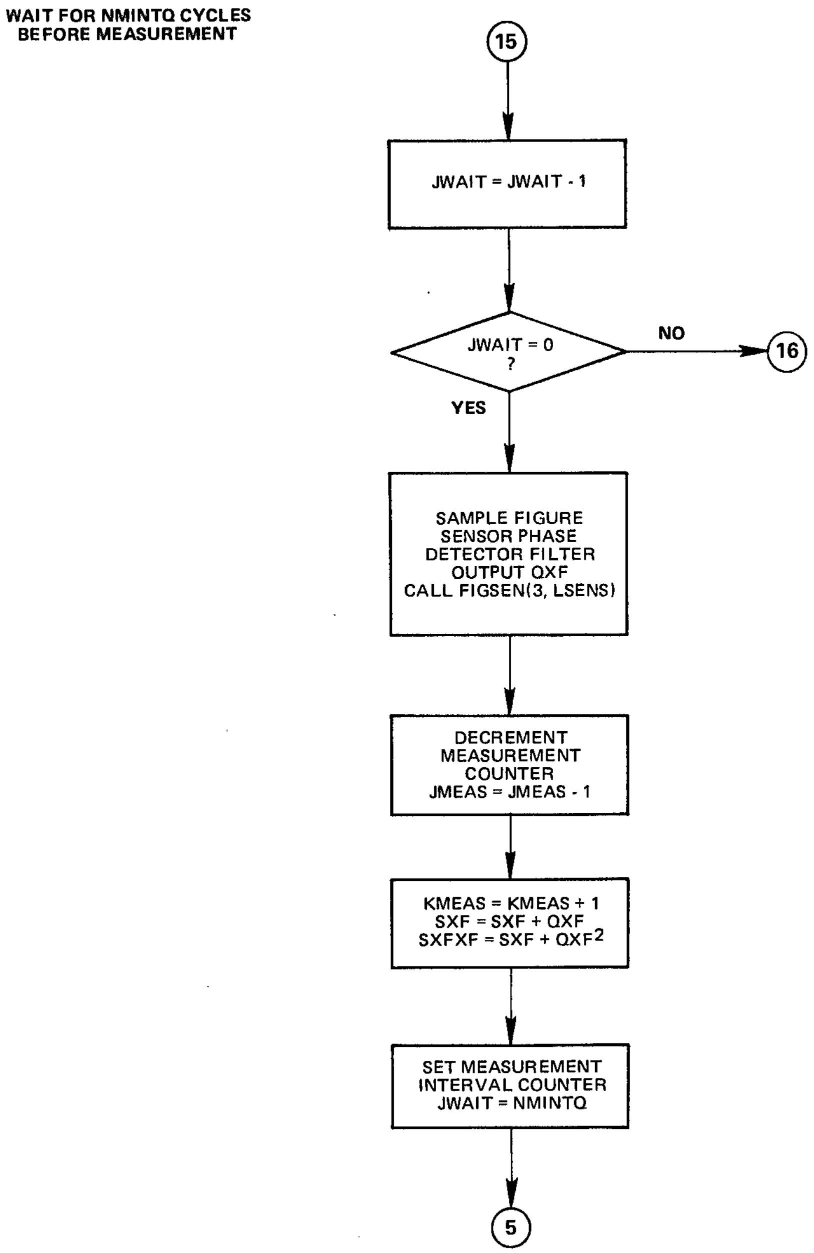

WAIT FOR NMINTQ CYCLES
BEFORE MEASUREMENT
15
JWAIT = JWAIT - 1
JWAIT = 0
?
NO
16
YES
SAMPLE FIGURE
SENSOR PHASE
DETECTOR FILTER
OUTPUT QXF
CALL FIGSEN(3, LSENS)
DECREMENT
MEASUREMENT
COUNTER
JMEAS = JMEAS - 1
KMEAS = KMEAS + 1
SXF = SXF + QXF
SXFXF = SXF + QXF^2
SET MEASUREMENT
INTERVAL COUNTER
JWAIT = NMINTQ
5

Fig. 4.7.4 Cont.

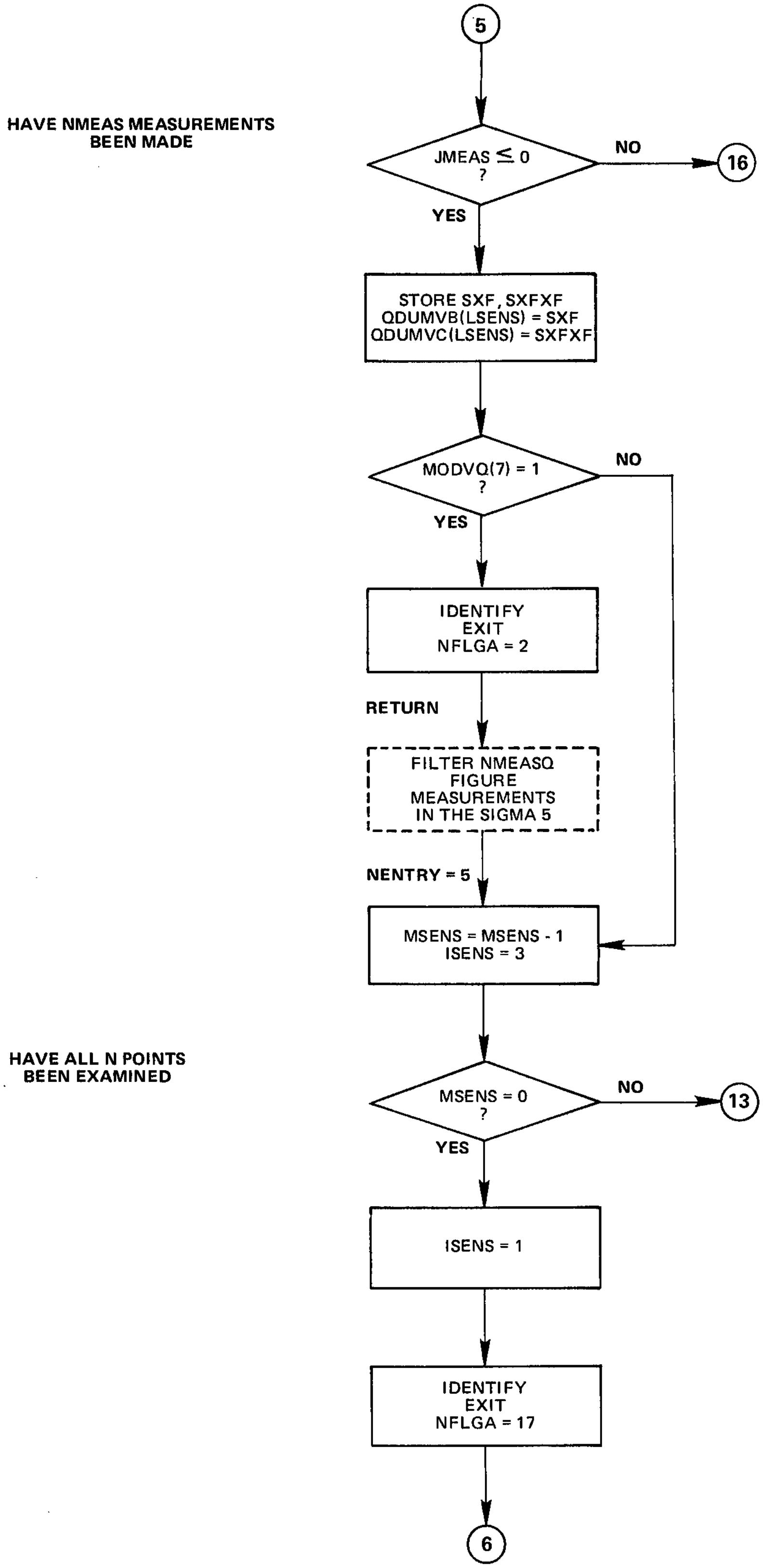

5
HAVE NMEAS MEASUREMENTS BEEN MADE
JMEAS ≤ 0 ?
NO
16
YES
STORE SXF, SXFXF
QDUMVB(LSENS) = SXF
QDUMVC(LSENS) = SXFXF
MODVQ(7) = 1 ?
NO
YES
IDENTIFY
EXIT
NFLGA = 2
RETURN
FILTER NMEASQ
FIGURE
MEASUREMENTS
IN THE SIGMA 5
NENTRY = 5
MSENS = MSENS - 1
ISENS = 3
HAVE ALL N POINTS BEEN EXAMINED
MSENS = 0 ?
NO
13
YES
ISENS = 1
IDENTIFY
EXIT
NFLGA = 17
6

Fig. 4.7.4 Cont.

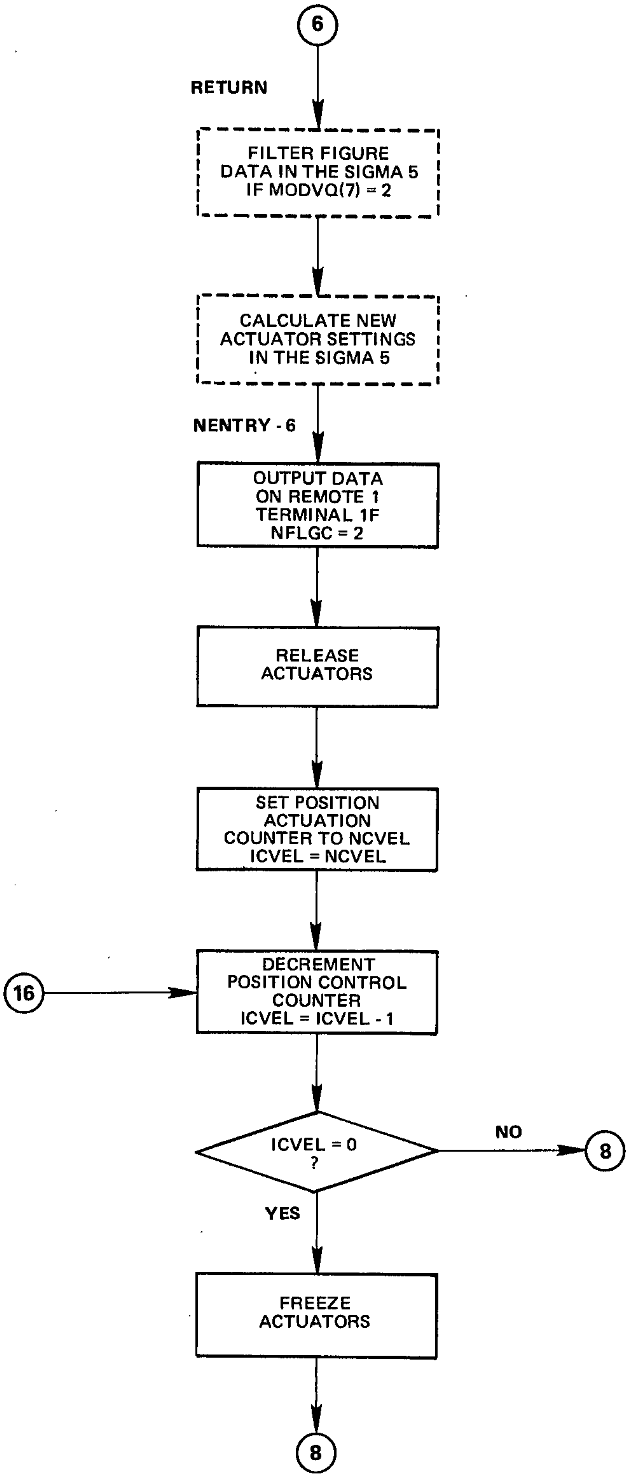
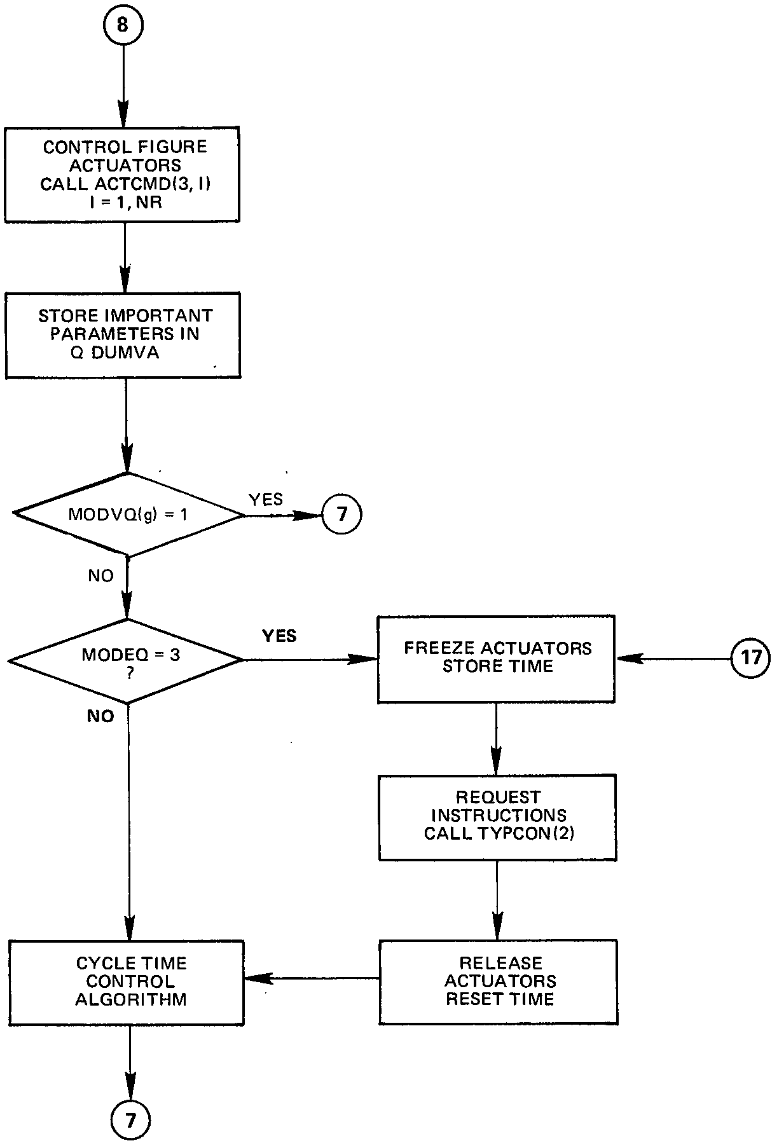

6
RETURN
FILTER FIGURE DATA IN THE SIGMA 5 IF MODVQ(7) = 2
CALCULATE NEW ACTUATOR SETTINGS IN THE SIGMA 5
NENTRY - 6
OUTPUT DATA ON REMOTE 1 TERMINAL 1F NFLGC = 2
RELEASE ACTUATORS
SET POSITION ACTUATION COUNTER TO NCVEL ICVEL = NCVEL
16
DECREMENT POSITION CONTROL COUNTER ICVEL = ICVEL - 1
ICVEL = 0 ?
NO
8
YES
FREEZE ACTUATORS
8

Fig. 4.7.4 Cont.


8
CONTROL FIGURE ACTUATORS CALL ACTCMD(3, I) I = 1, NR
STORE IMPORTANT PARAMETERS IN Q DUMVA
MODVQ(g) = 1
YES
7
NO
MODEQ = 3 ?
YES
NO
FREEZE ACTUATORS STORE TIME
17
REQUEST INSTRUCTIONS CALL TYPCON(2)
RELEASE ACTUATORS RESET TIME
CYCLE TIME CONTROL ALGORITHM
7

STOP CONTROL SYSTEM IF MODEQ = 3

Fig. 4.7.4 Cont.

FIGSEN 1/1

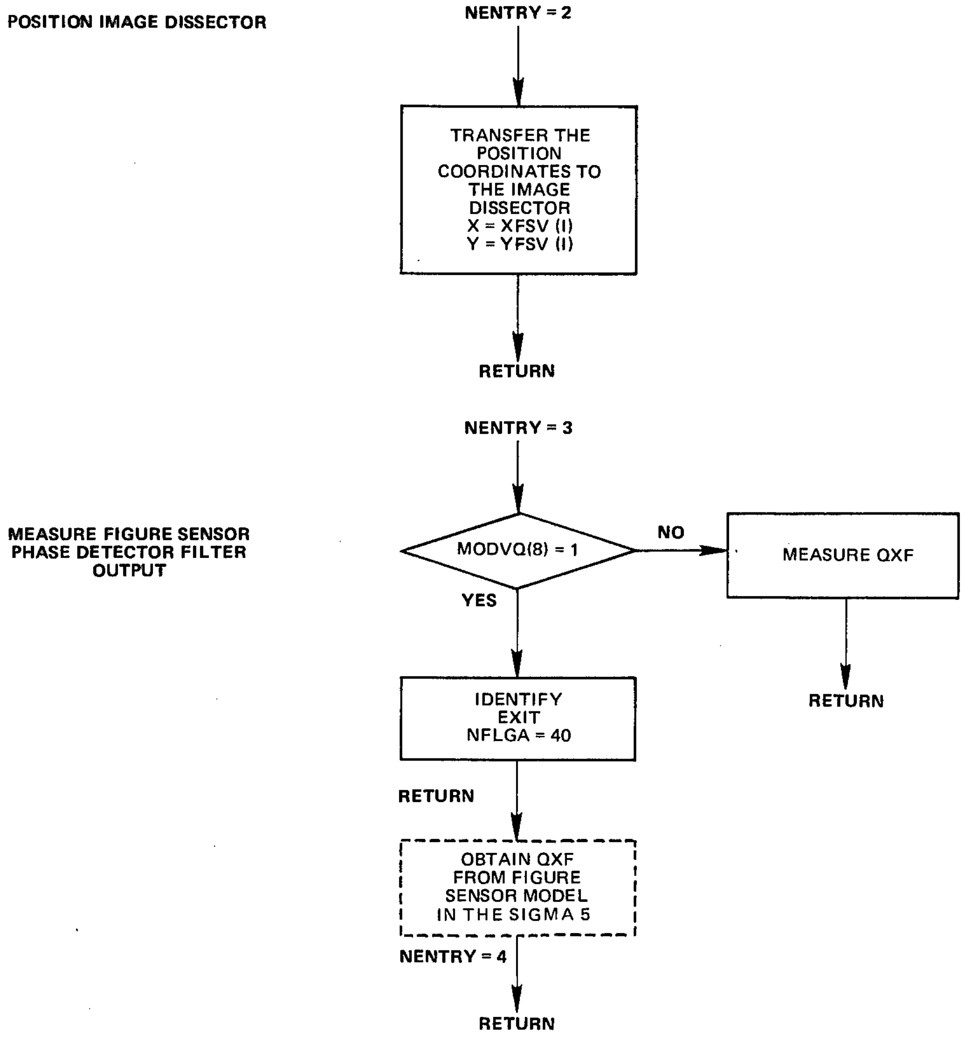

POSITION IMAGE DISSECTOR
NENTRY = 2
TRANSFER THE POSITION COORDINATES TO THE IMAGE DISSECTOR
X = XFSV (I)
Y = YFSV (I)
RETURN
NENTRY = 3
MEASURE FIGURE SENSOR PHASE DETECTOR FILTER OUTPUT
MODVQ(8) = 1
NO
MEASURE QXF
RETURN
YES
IDENTIFY EXIT
NFLGA = 40
RETURN
OBTAIN QXF FROM FIGURE SENSOR MODEL IN THE SIGMA 5
NENTRY = 4
RETURN

Fig. 4.7.5 FIGSEN flow diagram.

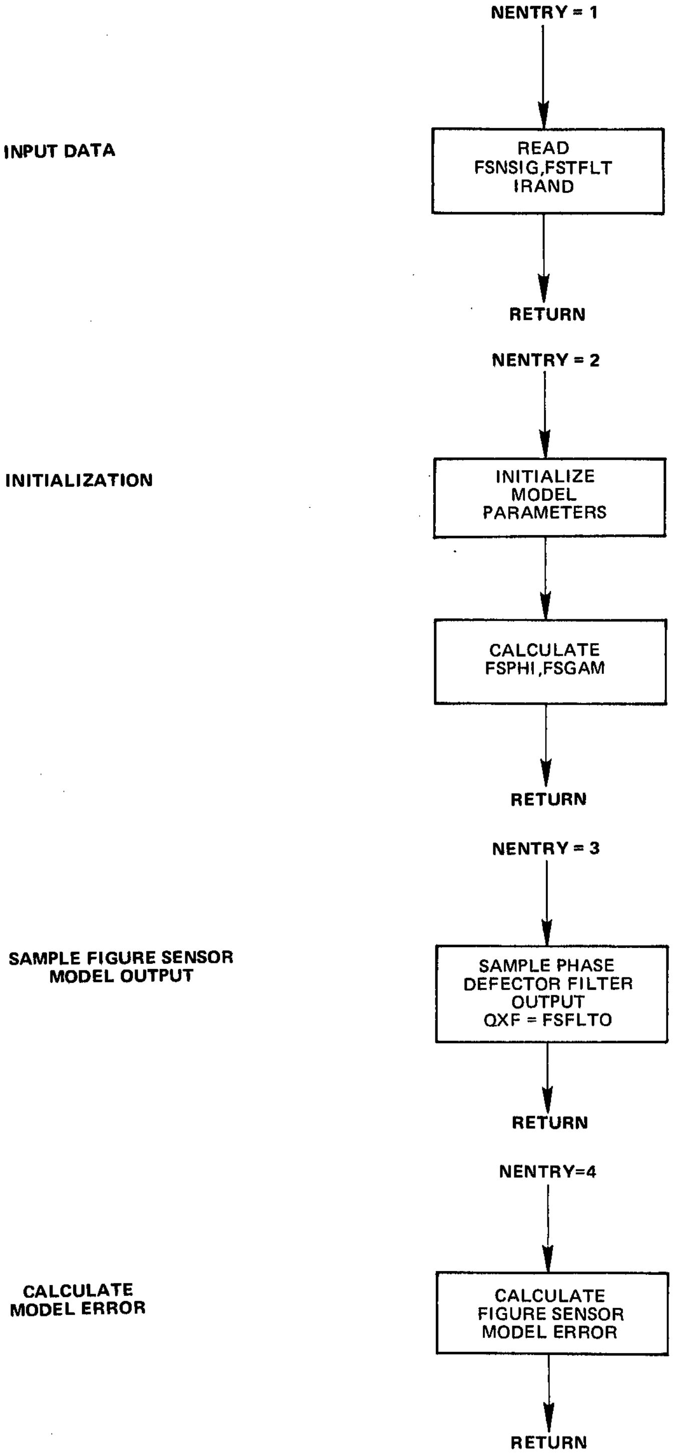
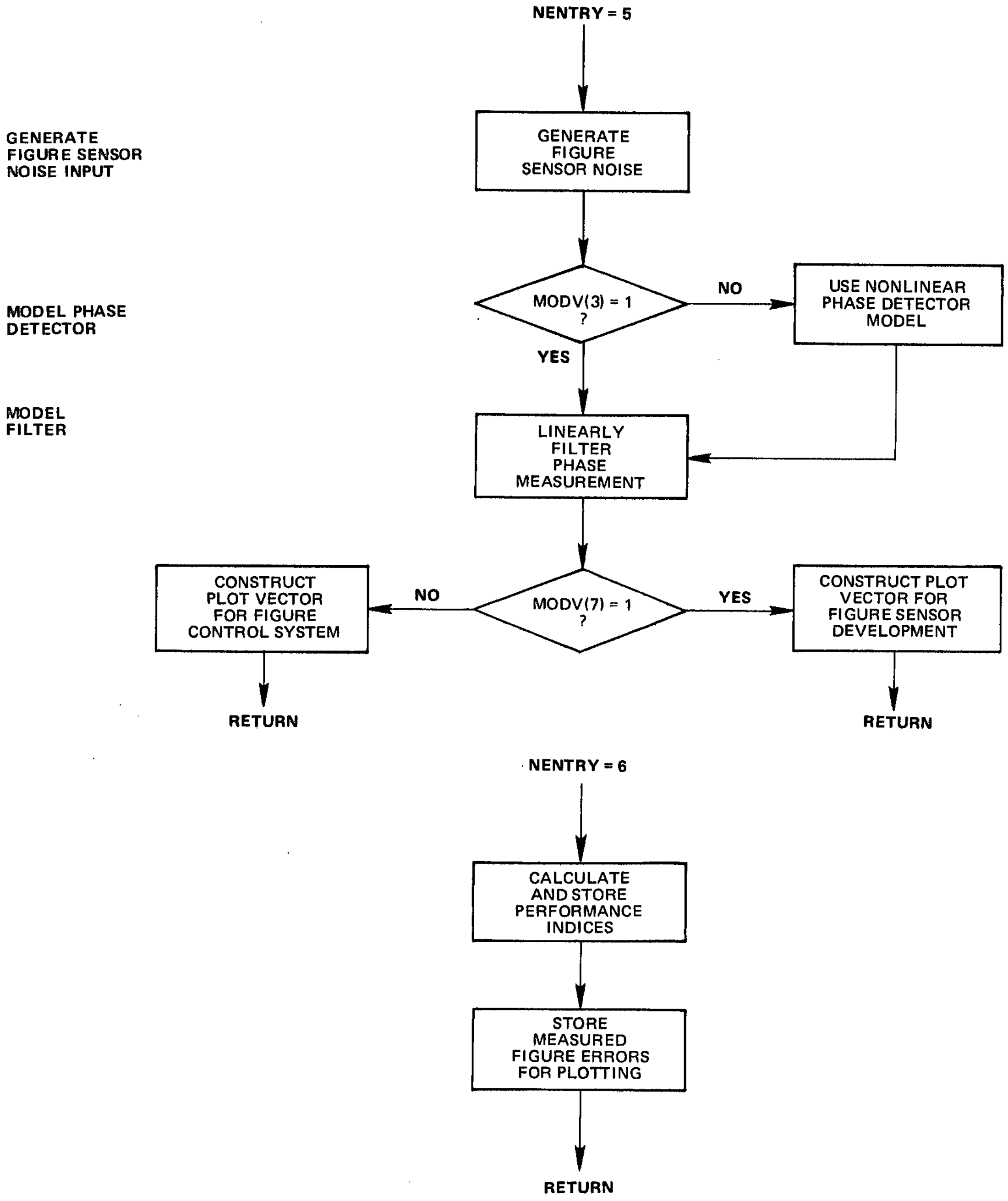


Fig. 4.7.6 FSMDL flow diagram.

FSMDL 2/2



NENTRY = 5
GENERATE FIGURE SENSOR NOISE INPUT
GENERATE FIGURE SENSOR NOISE
MODEL PHASE DETECTOR
MODV(3) = 1 ?
NO
USE NONLINEAR PHASE DETECTOR MODEL
YES
MODEL FILTER
LINEARLY FILTER PHASE MEASUREMENT
CONSTRUCT PLOT VECTOR FOR FIGURE CONTROL SYSTEM
NO
MODV(7) = 1 ?
YES
CONSTRUCT PLOT VECTOR FOR FIGURE SENSOR DEVELOPMENT
RETURN
RETURN
NENTRY = 6
CALCULATE AND STORE PERFORMANCE INDICES
STORE MEASURED FIGURE ERRORS FOR PLOTTING
RETURN

Fig. 4.7.6 Cont.

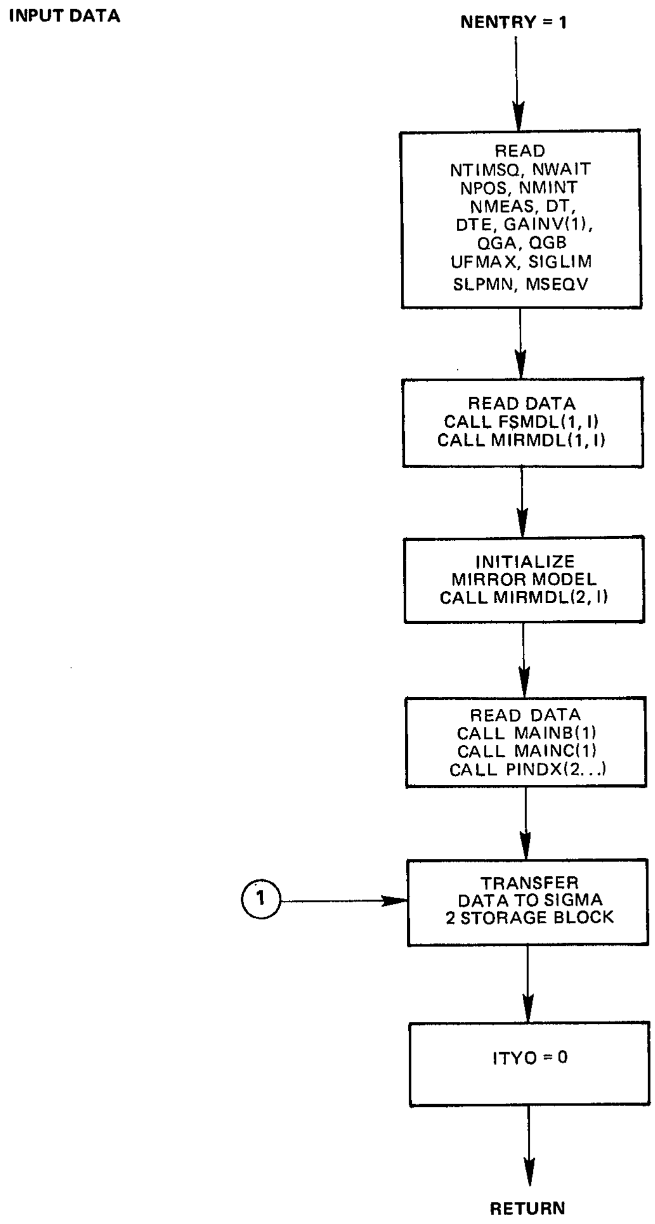

INPUT DATA
NENTRY = 1
READ NTIMSQ, NWAIT NPOS, NMINT NMEAS, DT, DTE, GAINV(1), QGA, QGB UFMAX, SIGLIM SLPMN, MSEQV
READ DATA CALL FSMDL(1, I) CALL MIRMDL(1, I)
INITIALIZE MIRROR MODEL CALL MIRMDL(2, I)
READ DATA CALL MAINB(1) CALL MAINC(1) CALL PINDX(2...)
1
TRANSFER DATA TO SIGMA 2 STORAGE BLOCK
ITYO = 0
RETURN

Fig. 4.7.7 MAINA flow diagram.

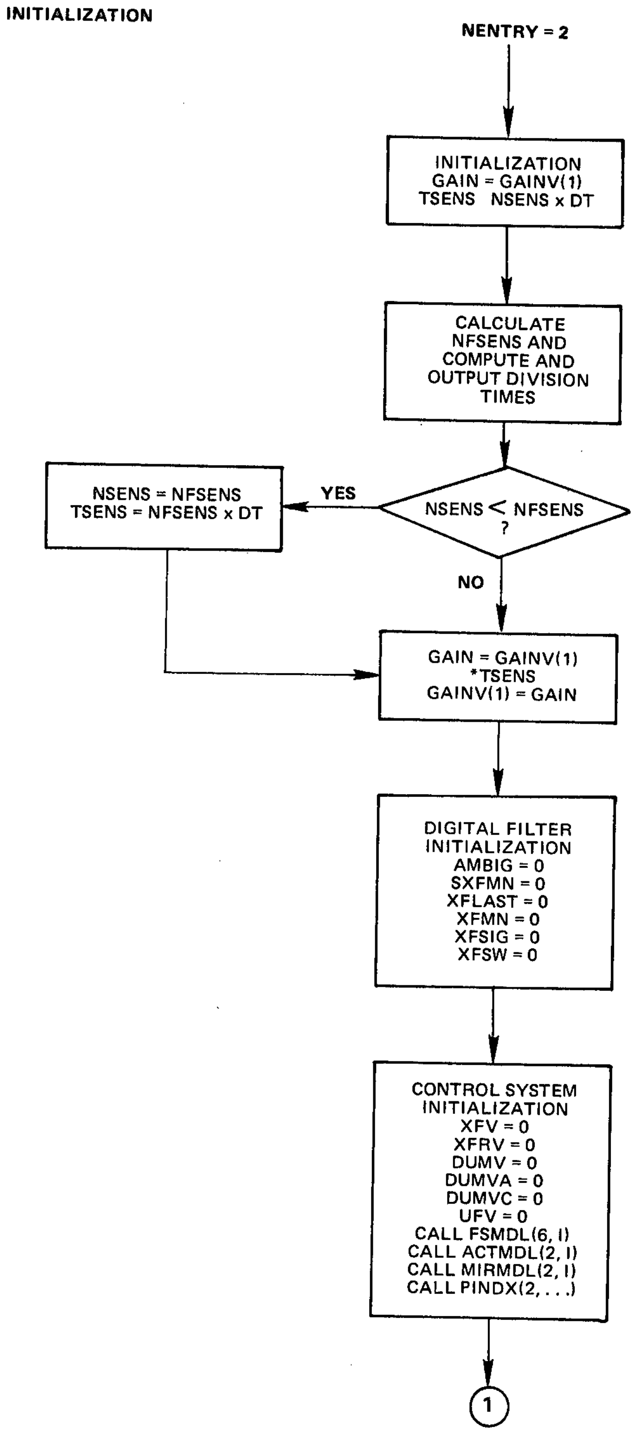

INITIALIZATION
NENTRY = 2
INITIALIZATION
GAIN = GAINV(1)
TSENS   NSENS x DT
CALCULATE
NFSENS AND
COMPUTE AND
OUTPUT DIVISION
TIMES
NSENS < NFSENS
?
YES
NSENS = NFSENS
TSENS = NFSENS x DT
NO
GAIN = GAINV(1)
*TSENS
GAINV(1) = GAIN
DIGITAL FILTER
INITIALIZATION
AMBIG = 0
SXFMN = 0
XFLAST = 0
XFMN = 0
XFSIG = 0
XFSW = 0
CONTROL SYSTEM
INITIALIZATION
XFV = 0
XFRV = 0
DUMV = 0
DUMVA = 0
DUMVC = 0
UFV = 0
CALL FSMDL(6, I)
CALL ACTMDL(2, I)
CALL MIRMDL(2, I)
CALL PINDX(2, . . .)
1

Fig. 4.7.7   Cont.

DATA TRANSFER TO THE SIGMA 2

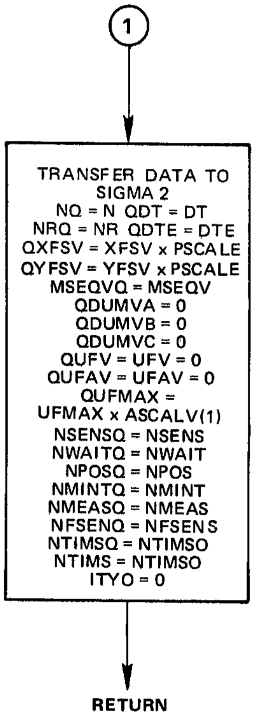


Fig. 4.7.7 Cont.

CONTROL CALCULATION

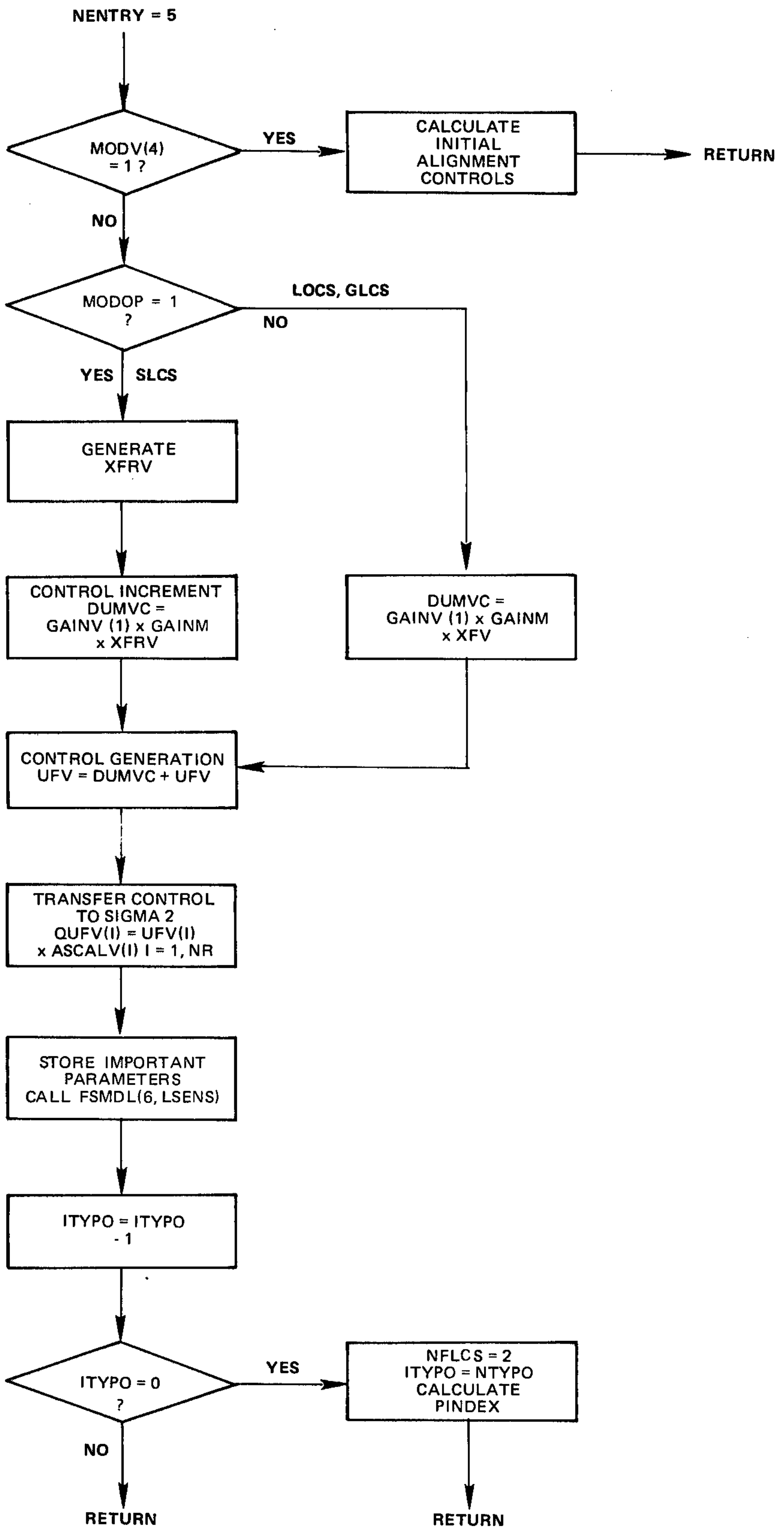

NENTRY = 5
MODV(4) = 1 ?
YES
CALCULATE INITIAL ALIGNMENT CONTROLS
RETURN
NO
MODOP = 1 ?
LOCS, GLCS
NO
YES
SLCS
GENERATE XFRV
CONTROL INCREMENT DUMVC = GAINV (1) x GAINM x XFRV
DUMVC = GAINV (1) x GAINM x XFV
CONTROL GENERATION UFV = DUMVC + UFV
TRANSFER CONTROL TO SIGMA 2 QUFV(I) = UFV(I) x ASCALV(I) I = 1, NR
STORE IMPORTANT PARAMETERS CALL FSMDL(6, LSENS)
ITYPO = ITYPO - 1
ITYPO = 0 ?
YES
NFLCS = 2 ITYPO = NTYPO CALCULATE PINDEX
NO
RETURN
RETURN

Fig. 4.7.7 Cont.

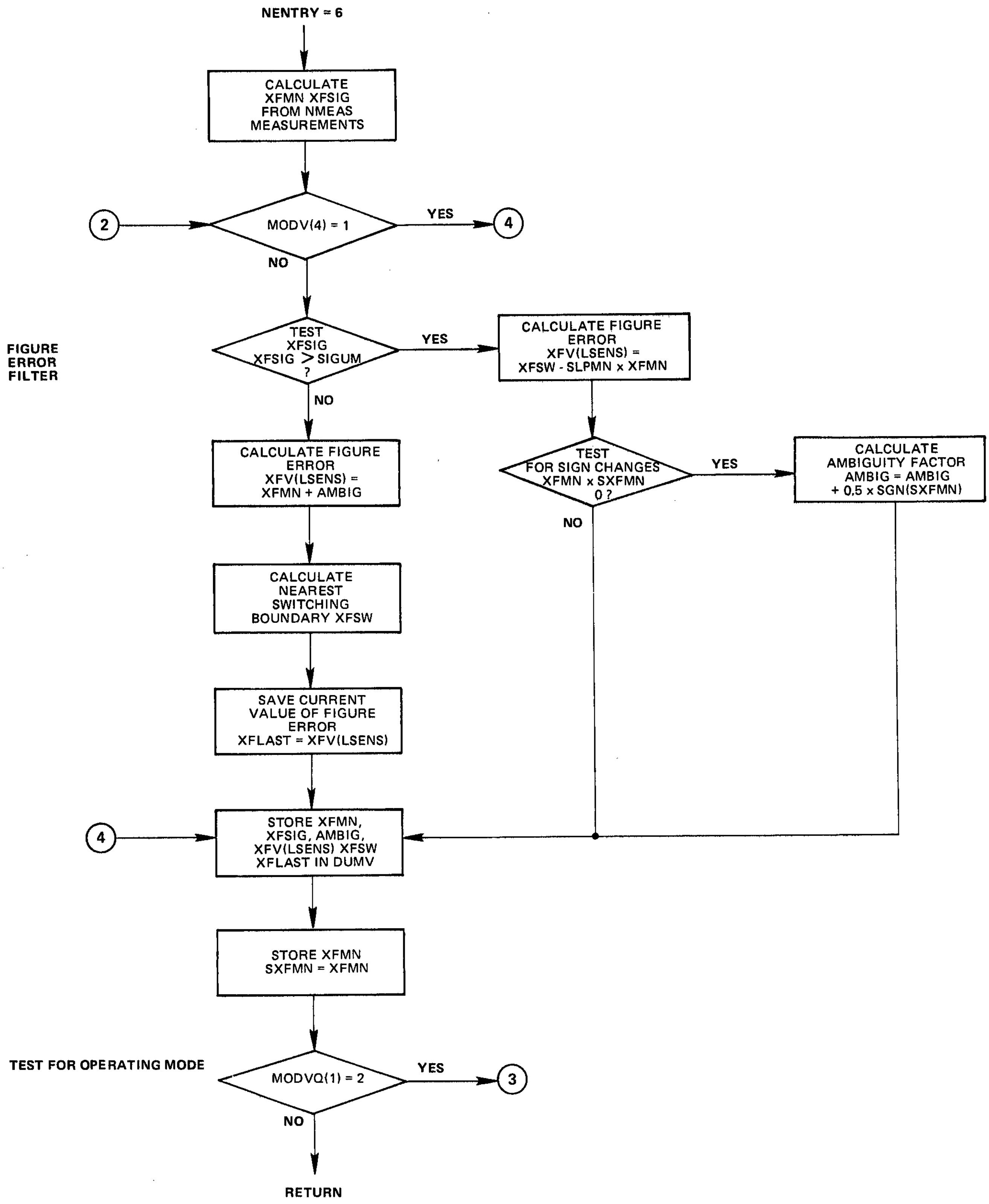

NENTRY = 6
CALCULATE XFMN XFSIG FROM NMEAS MEASUREMENTS
2
MODV(4) = 1
YES
4
NO
FIGURE ERROR FILTER
TEST XFSIG XFSIG > SIGUM ?
YES
CALCULATE FIGURE ERROR XFV(LSENS) = XFSW - SLPMN x XFMN
NO
CALCULATE FIGURE ERROR XFV(LSENS) = XFMN + AMBIG
TEST FOR SIGN CHANGES XFMN x SXFMN 0 ?
YES
CALCULATE AMBIGUITY FACTOR AMBIG = AMBIG + 0.5 x SGN(SXFMN)
NO
CALCULATE NEAREST SWITCHING BOUNDARY XFSW
SAVE CURRENT VALUE OF FIGURE ERROR XFLAST = XFV(LSENS)
4
STORE XFMN, XFSIG, AMBIG, XFV(LSENS) XFSW XFLAST IN DUMV
STORE XFMN SXFMN = XFMN
TEST FOR OPERATING MODE
MODVQ(1) = 2
YES
3
NO
RETURN

Fig. 4.7.7 Cont.

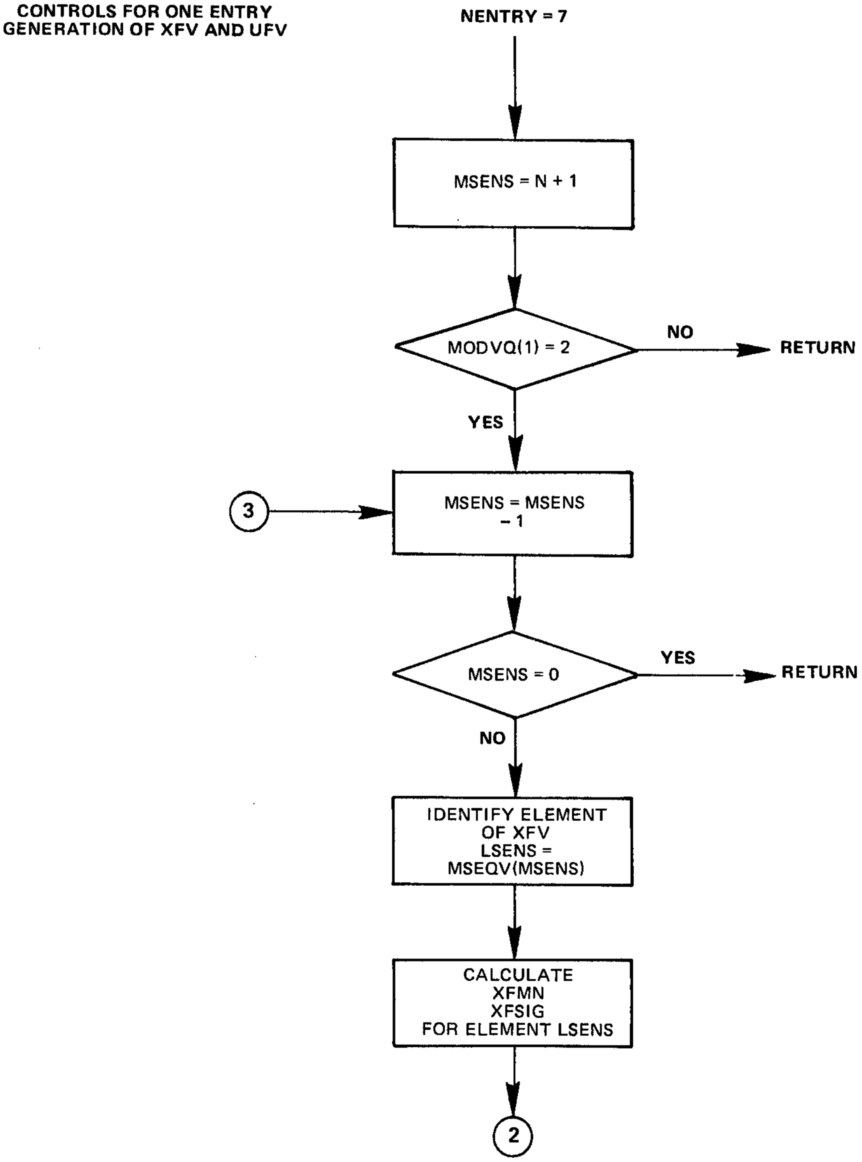

CONTROLS FOR ONE ENTRY
GENERATION OF XFV AND UFV
NENTRY = 7
MSENS = N + 1
MODVQ(1) = 2
NO
RETURN
YES
3
MSENS = MSENS
− 1
MSENS = 0
YES
RETURN
NO
IDENTIFY ELEMENT
OF XFV
LSENS =
MSEQV(MSENS)
CALCULATE
XFMN
XFSIG
FOR ELEMENT LSENS
2

Fig. 4.7.7 Cont.

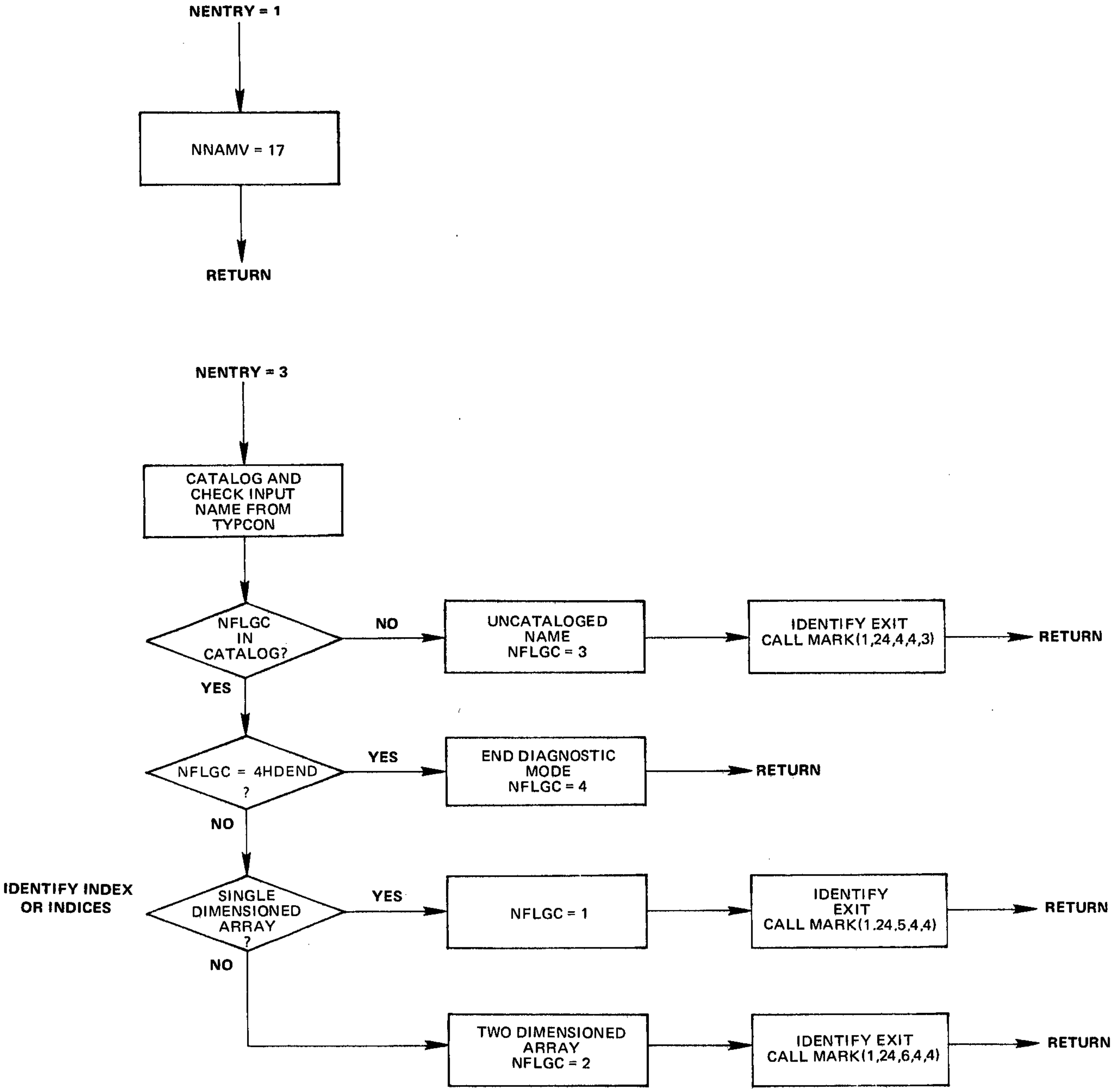

NENTRY = 1
NNAMV = 17
RETURN
NENTRY = 3
CATALOG AND CHECK INPUT NAME FROM TYPCON
NFLGC IN CATALOG?
NO
UNCATALOGED NAME NFLGC = 3
IDENTIFY EXIT CALL MARK(1,24,4,4,3)
RETURN
YES
NFLGC = 4HDEND ?
YES
END DIAGNOSTIC MODE NFLGC = 4
RETURN
NO
IDENTIFY INDEX OR INDICES
SINGLE DIMENSIONED ARRAY ?
YES
NFLGC = 1
IDENTIFY EXIT CALL MARK(1.24,5,4,4)
RETURN
NO
TWO DIMENSIONED ARRAY NFLGC = 2
IDENTIFY EXIT CALL MARK(1,24,6,4,4)
RETURN

Fig. 4.7.8 MAINB flow diagram.

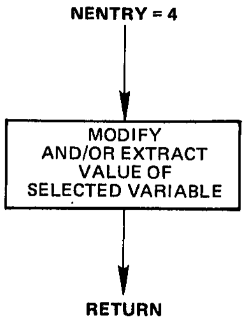

NENTRY = 4
MODIFY AND/OR EXTRACT VALUE OF SELECTED VARIABLE
RETURN

Fig. 4.7.8 Cont.

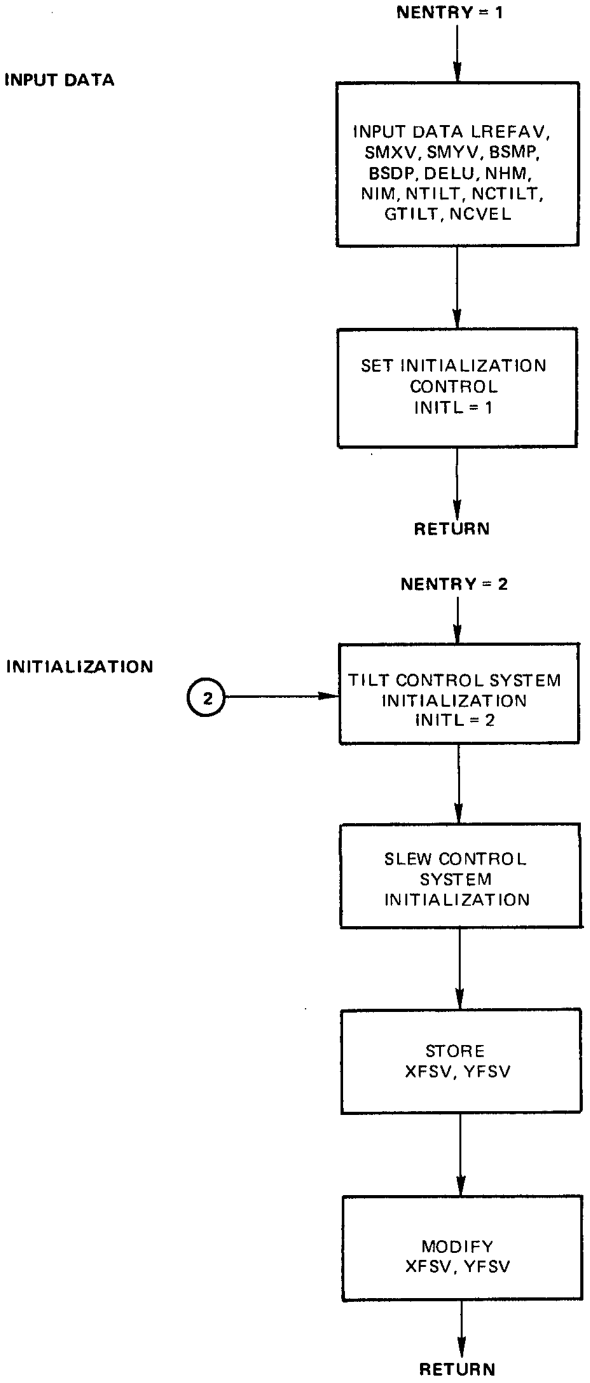

NENTRY = 1
INPUT DATA
INPUT DATA LREFAV, SMXV, SMYV, BSMP, BSDP, DELU, NHM, NIM, NTILT, NCTILT, GTILT, NCVEL
SET INITIALIZATION CONTROL INITL = 1
RETURN
NENTRY = 2
INITIALIZATION
2
TILT CONTROL SYSTEM INITIALIZATION INITL = 2
SLEW CONTROL SYSTEM INITIALIZATION
STORE XFSV, YFSV
MODIFY XFSV, YFSV
RETURN

Fig. 4.7.9 MAINC flow diagram.

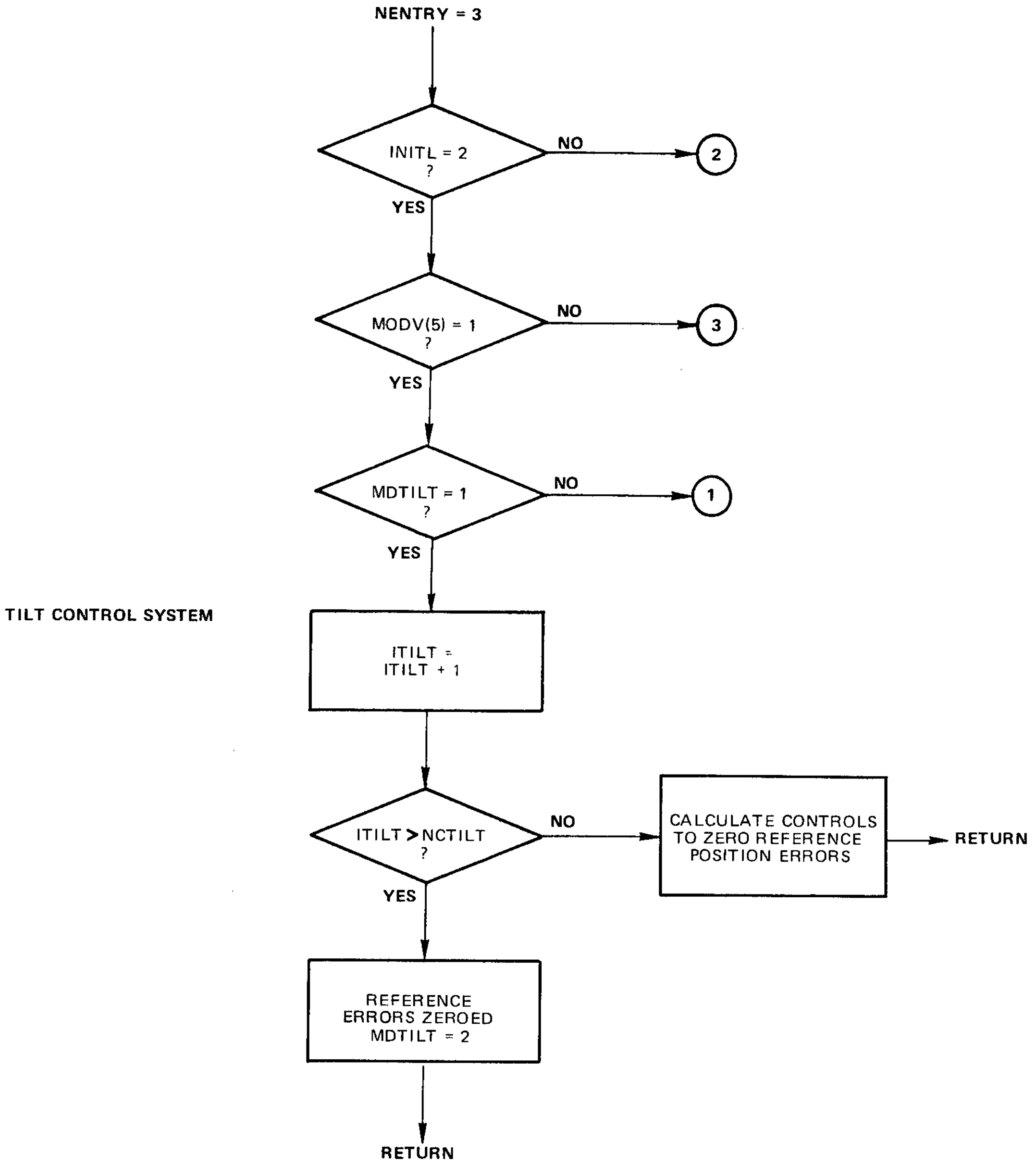

NENTRY = 3
INITL = 2 ?
NO
2
YES
MODV(5) = 1 ?
NO
3
YES
MDTILT = 1 ?
NO
1
YES
TILT CONTROL SYSTEM
ITILT = ITILT + 1
ITILT > NCTILT ?
NO
CALCULATE CONTROLS TO ZERO REFERENCE POSITION ERRORS
RETURN
YES
REFERENCE ERRORS ZEROED MDTILT = 2
RETURN

Fig. 4.7.9 Cont.

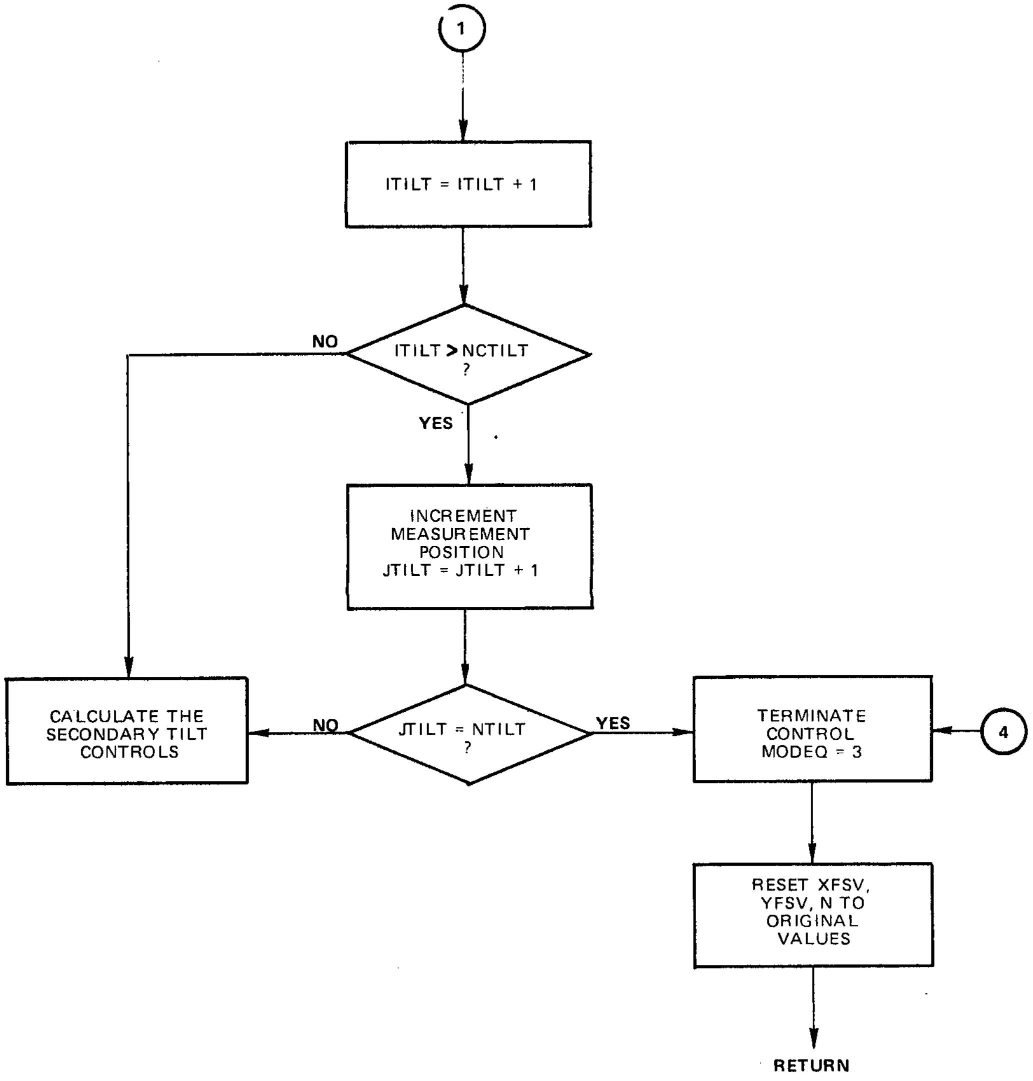

1
ITILT = ITILT + 1
ITILT > NCTILT ?
NO
YES
INCREMENT MEASUREMENT POSITION JTILT = JTILT + 1
JTILT = NTILT ?
NO
YES
CALCULATE THE SECONDARY TILT CONTROLS
TERMINATE CONTROL MODEQ = 3
4
RESET XFSV, YFSV, N TO ORIGINAL VALUES
RETURN

Fig. 4.7.9 Cont.

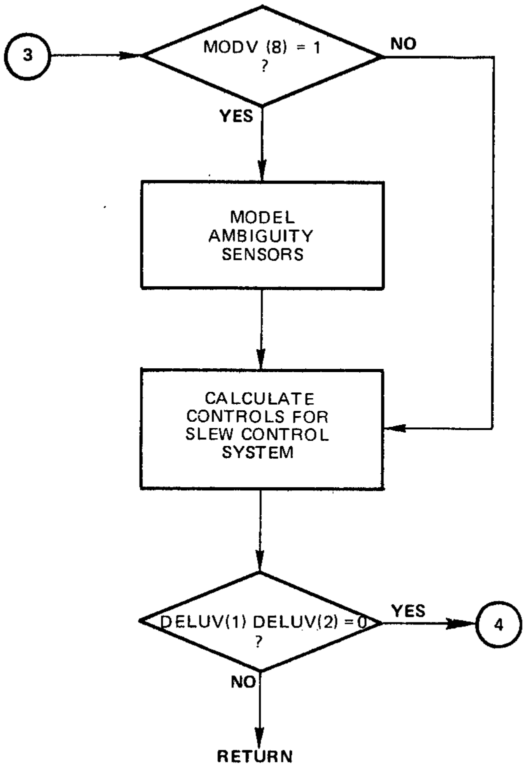

3
MODV (8) = 1
?
NO
YES
MODEL
AMBIGUITY
SENSORS
CALCULATE
CONTROLS FOR
SLEW CONTROL
SYSTEM
DELUV(1) DELUV(2) = 0
?
YES
4
NO
RETURN

Fig. 4.7.9 Cont.

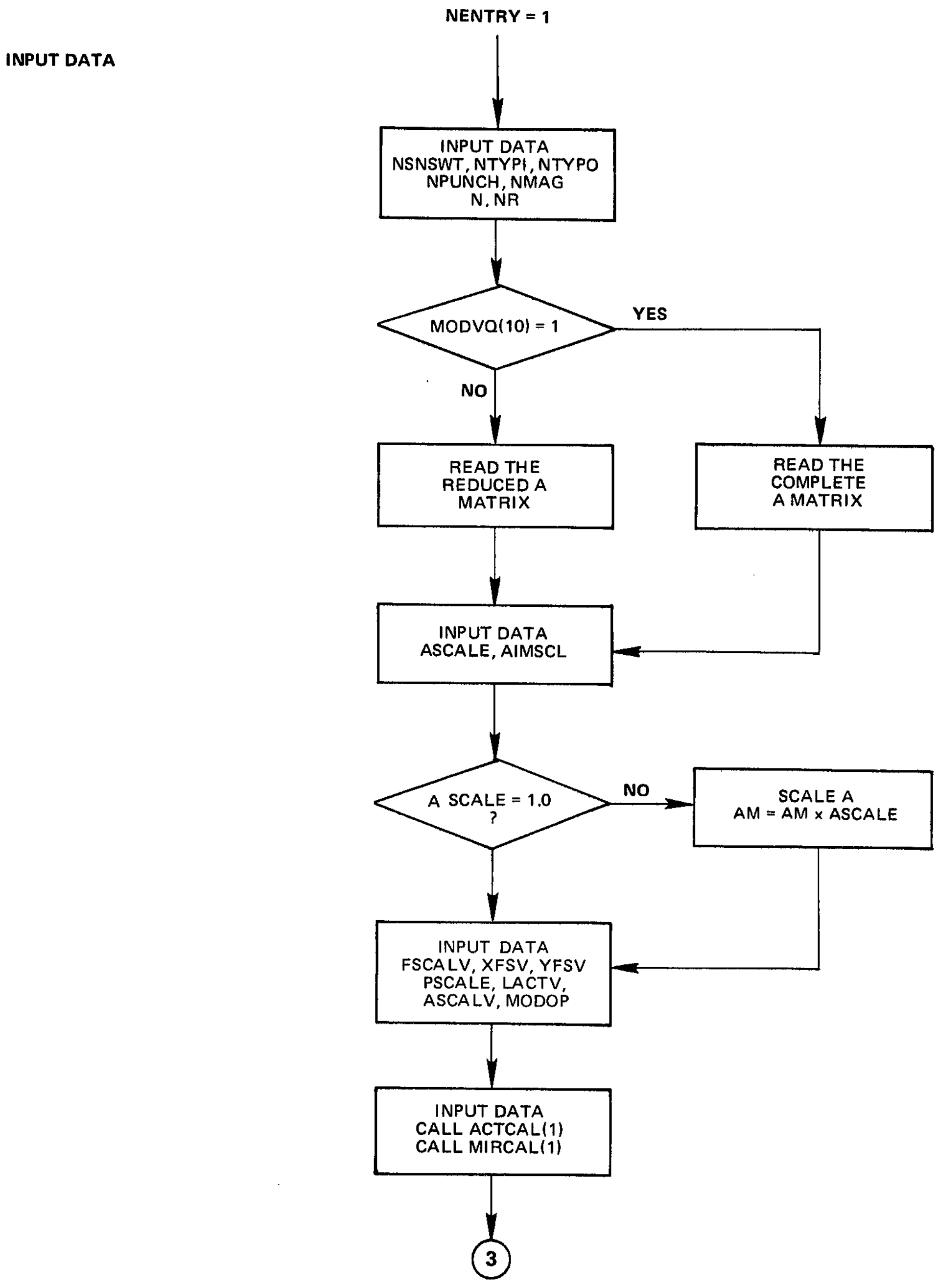

NENTRY = 1
INPUT DATA
INPUT DATA NSNSWT, NTYPI, NTYPO NPUNCH, NMAG N, NR
MODVQ(10) = 1
YES
NO
READ THE REDUCED A MATRIX
READ THE COMPLETE A MATRIX
INPUT DATA ASCALE, AIMSCL
A SCALE = 1.0 ?
NO
SCALE A AM = AM x ASCALE
INPUT DATA FSCALV, XFSV, YFSV PSCALE, LACTV, ASCALV, MODOP
INPUT DATA CALL ACTCAL(1) CALL MIRCAL(1)
3

Fig. 4.7.10 MFCS flow diagram.

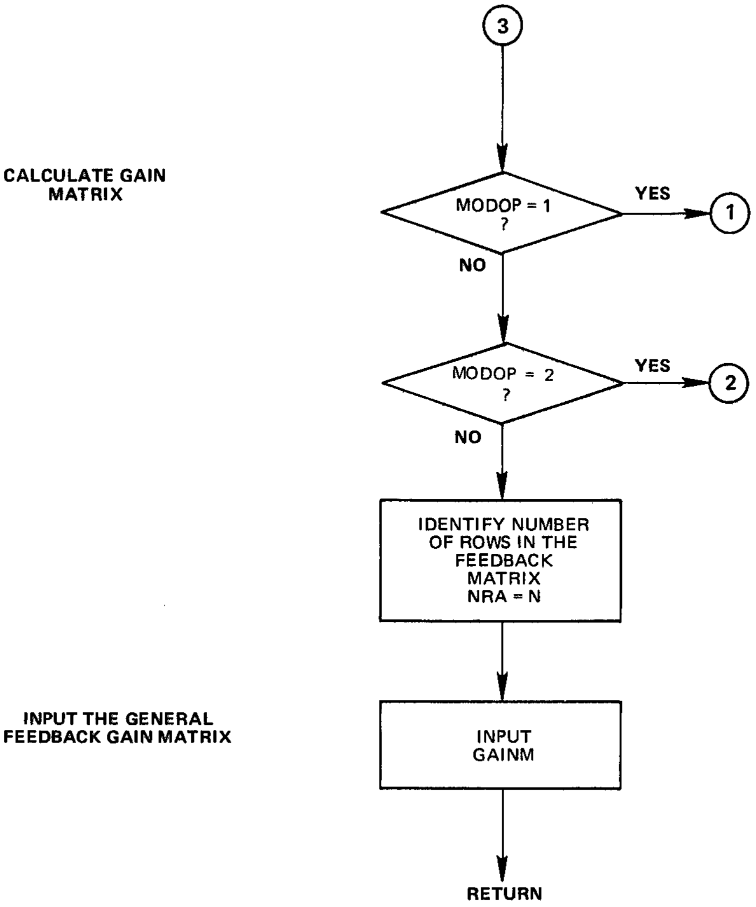
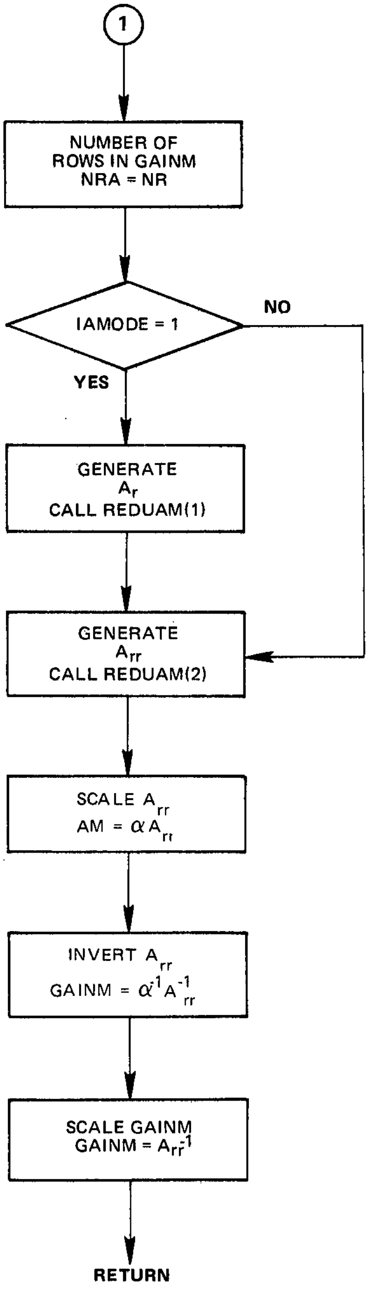

3
CALCULATE GAIN MATRIX
MODOP = 1 ?
YES
1
NO
MODOP = 2 ?
YES
2
NO
IDENTIFY NUMBER OF ROWS IN THE FEEDBACK MATRIX NRA = N
INPUT THE GENERAL FEEDBACK GAIN MATRIX
INPUT GAINM
RETURN

Fig. 4.7.10 Cont.


1
NUMBER OF ROWS IN GAINM NRA = NR
IAMODE = 1
NO
YES
GENERATE A_r CALL REDUAM(1)
GENERATE A_{rr} CALL REDUAM(2)
SCALE A_{rr} AM = αA_{rr}
INVERT A_{rr} GAINM = $\alpha^{-1} A_{rr}^{-1}$
SCALE GAINM GAINM = A_{rr}^{-1}
RETURN

CALCULATE THE SIMPLIFIED LINEAR GAIN MATRIX

Fig. 4.7.10 Cont.

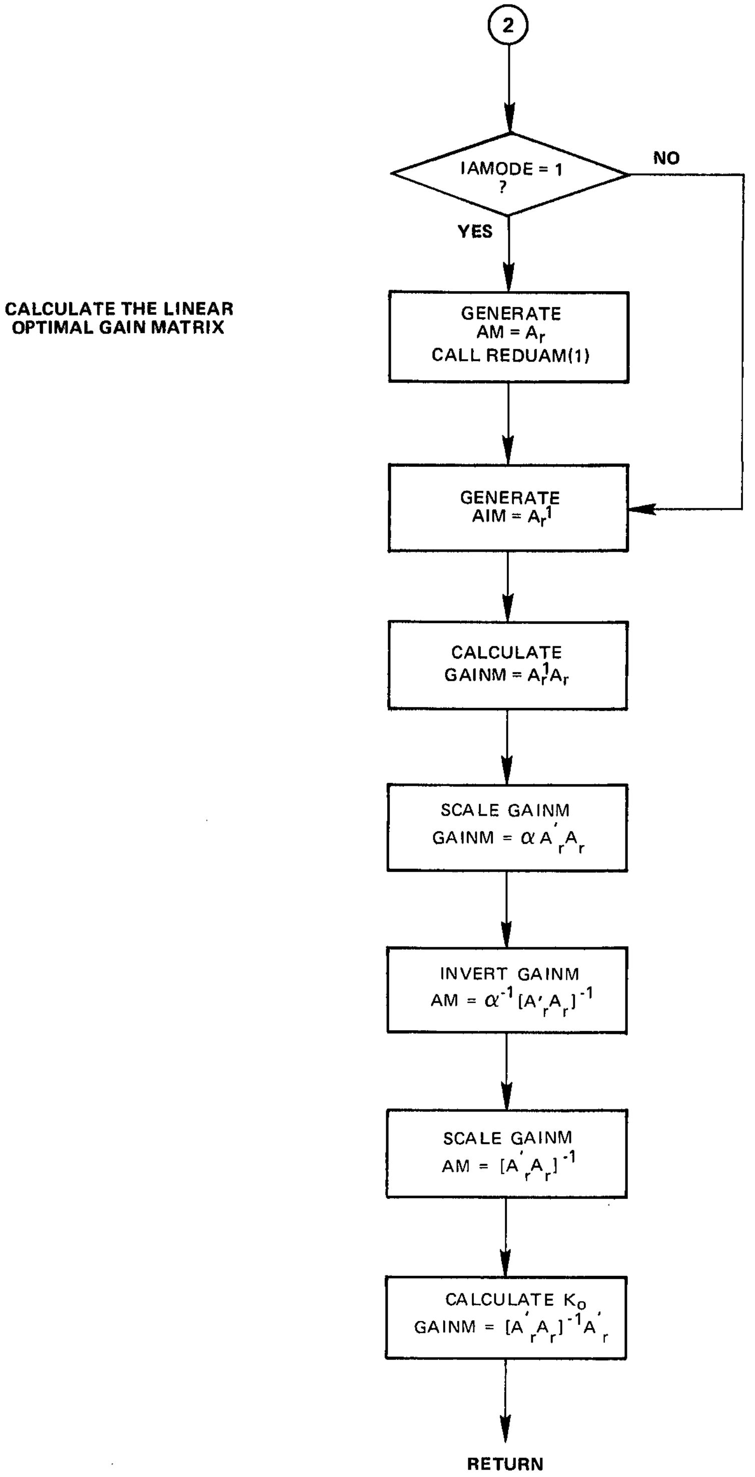

2
IAMODE = 1 ?
NO
YES
CALCULATE THE LINEAR OPTIMAL GAIN MATRIX
GENERATE AM = A_r CALL REDUAM(1)
GENERATE AIM = A_r^1
CALCULATE GAINM = A_r^1 A_r
SCALE GAINM GAINM = α A'_r A_r
INVERT GAINM AM = α^-1 [A'_r A_r]^-1
SCALE GAINM AM = [A'_r A_r]^-1
CALCULATE K_o GAINM = [A'_r A_r]^-1 A'_r
RETURN

Fig. 4.7.10 Cont.

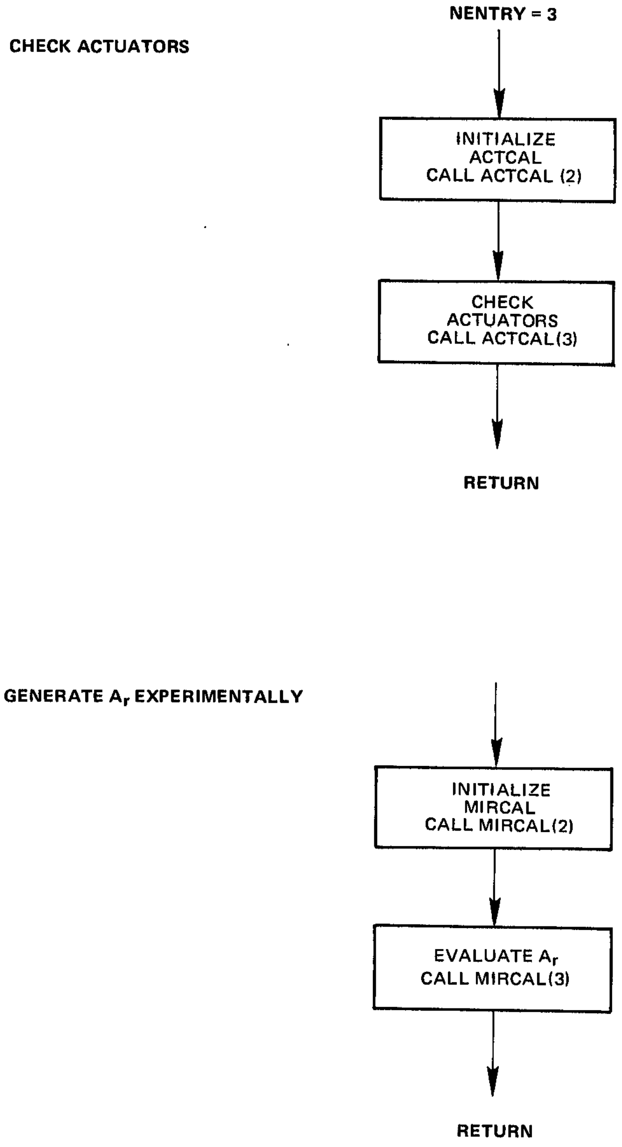

CHECK ACTUATORS
NENTRY = 3
INITIALIZE ACTCAL CALL ACTCAL (2)
CHECK ACTUATORS CALL ACTCAL(3)
RETURN
GENERATE A_r EXPERIMENTALLY
INITIALIZE MIRCAL CALL MIRCAL(2)
EVALUATE A_r CALL MIRCAL(3)
RETURN

Fig. 4.7.10 Cont.

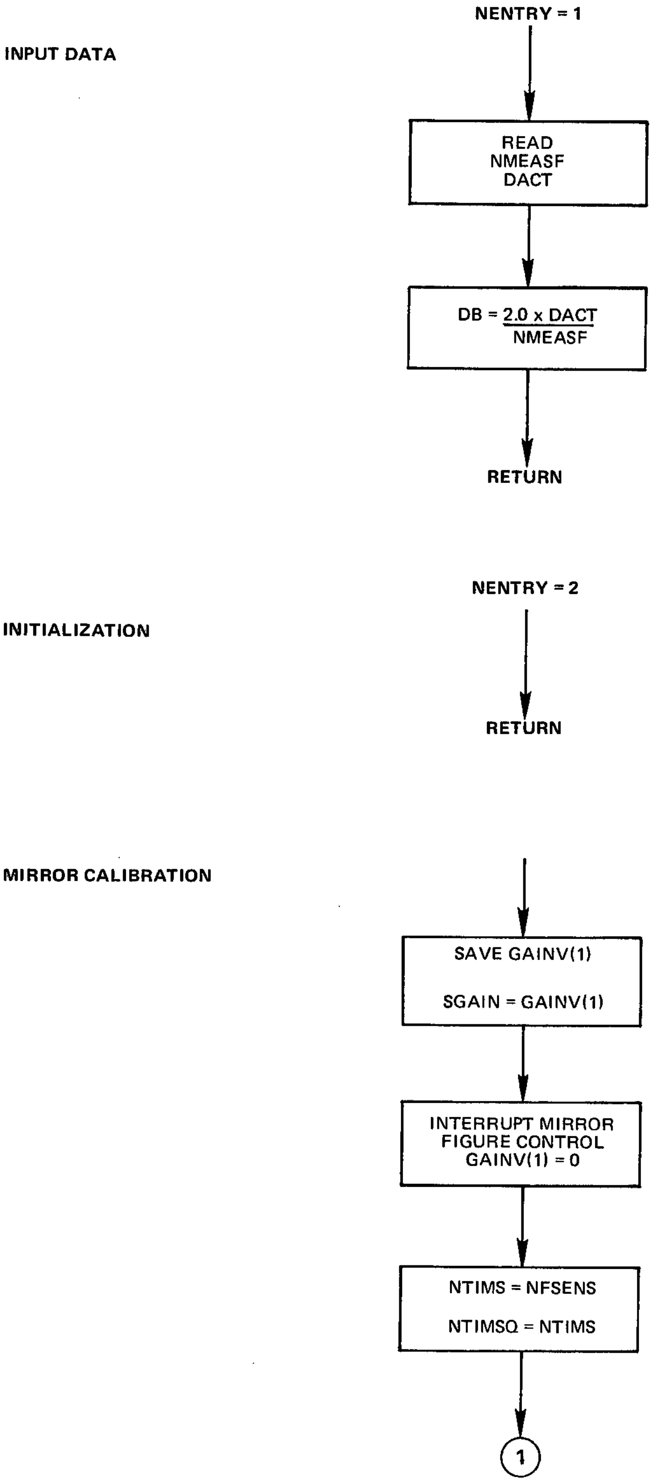


Fig. 4.7.11 MIRCAL flow diagram.

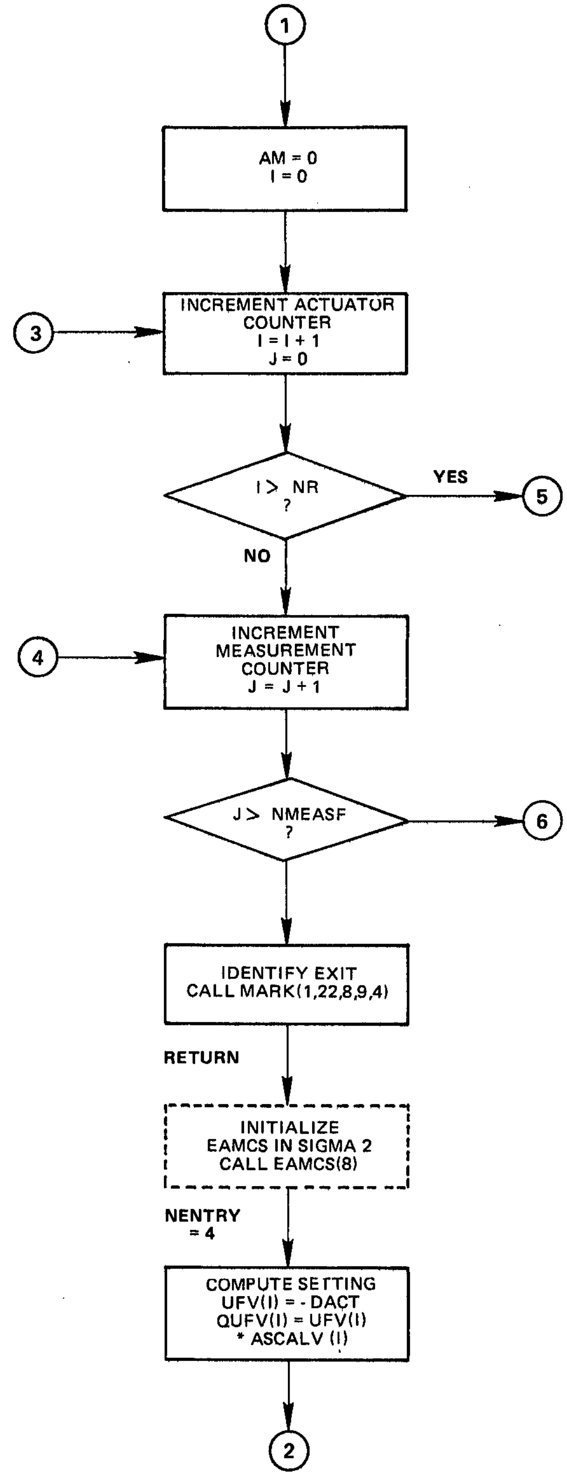


Fig. 4.7.11 Cont.

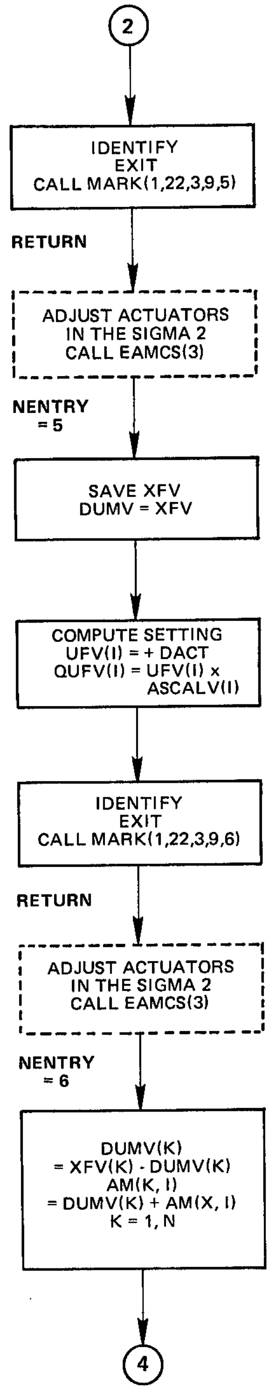


Fig. 4.7.11 Cont.

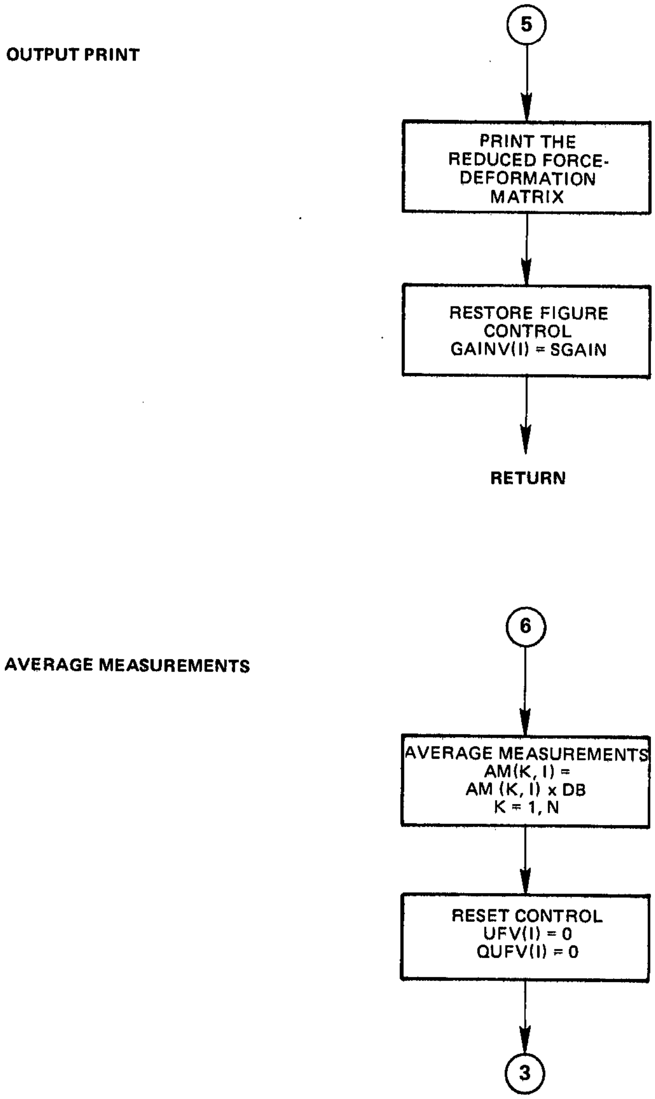

OUTPUT PRINT
5
PRINT THE REDUCED FORCE-DEFORMATION MATRIX
RESTORE FIGURE CONTROL GAINV(I) = SGAIN
RETURN
AVERAGE MEASUREMENTS
6
AVERAGE MEASUREMENTS AM(K, I) = AM (K, I) x DB K = 1, N
RESET CONTROL UFV(I) = 0 QUFV(I) = 0
3

Fig. 4.7.11 Cont.

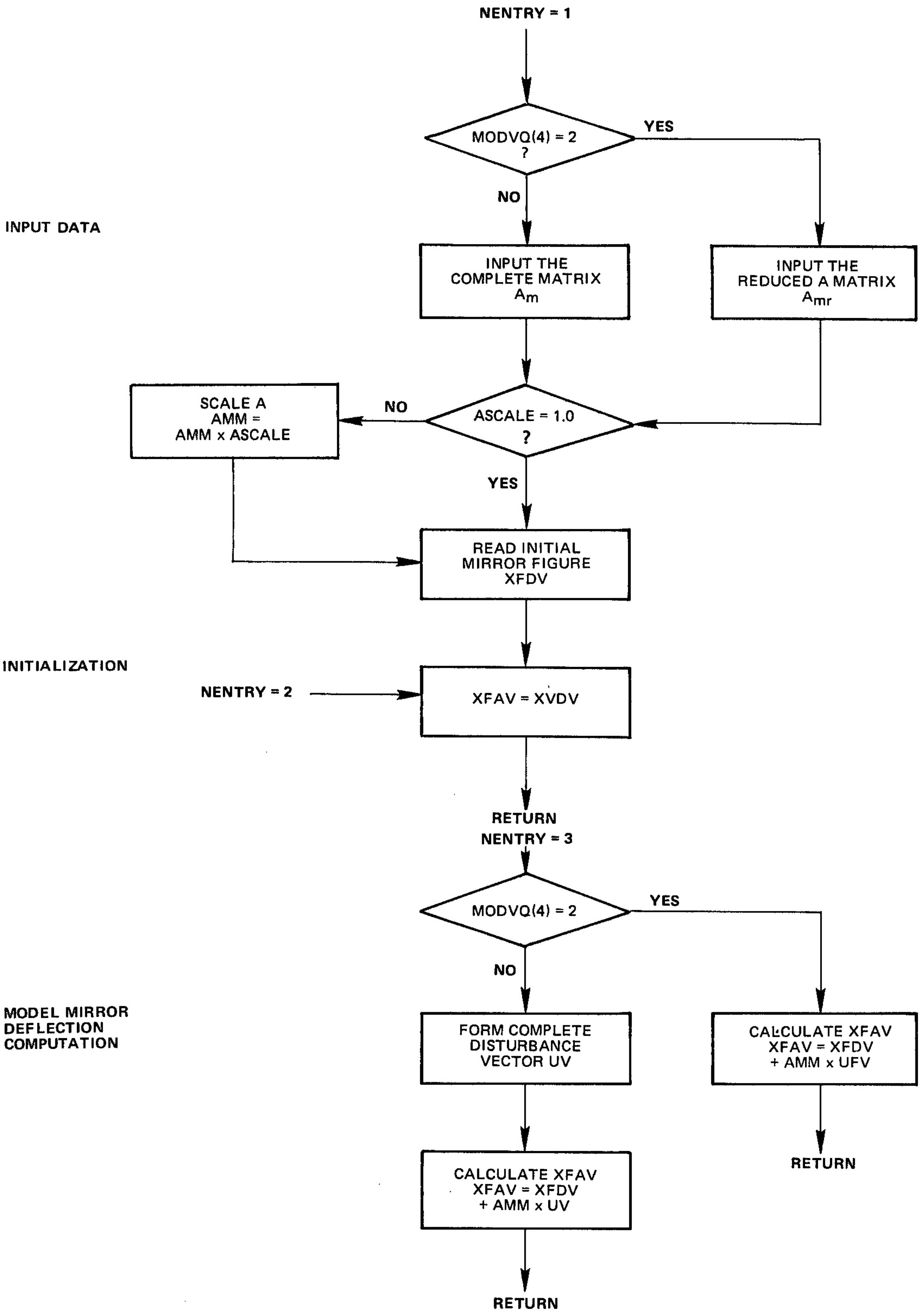

NENTRY = 1
MODVQ(4) = 2 ?
YES
NO
INPUT DATA
INPUT THE COMPLETE MATRIX A_m
INPUT THE REDUCED A MATRIX A_{mr}
SCALE A AMM = AMM x ASCALE
NO
ASCALE = 1.0 ?
YES
READ INITIAL MIRROR FIGURE XFDV
INITIALIZATION
NENTRY = 2
XFAV = XVDV
RETURN
NENTRY = 3
MODVQ(4) = 2
YES
NO
MODEL MIRROR DEFLECTION COMPUTATION
FORM COMPLETE DISTURBANCE VECTOR UV
CALCULATE XFAV XFAV = XFDV + AMM x UFV
RETURN
CALCULATE XFAV XFAV = XFDV + AMM x UV
RETURN

Fig. 4.7.12 MIRMDL flow diagram.

PINDX 1/1

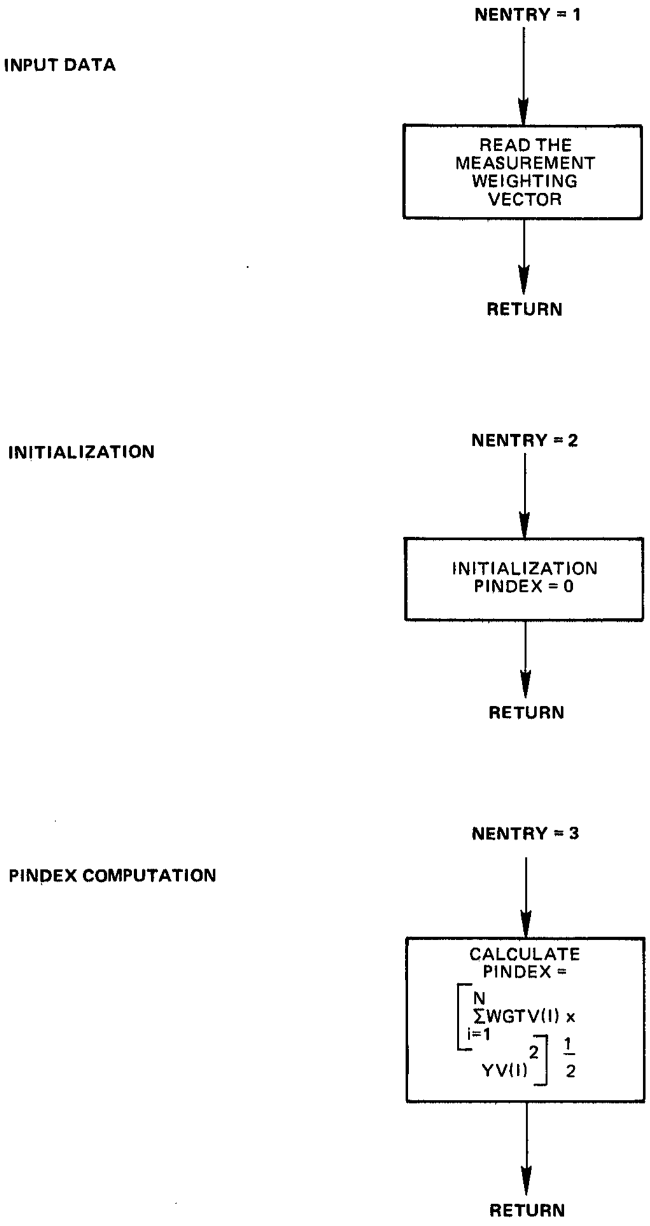

NENTRY = 1
INPUT DATA
READ THE MEASUREMENT WEIGHTING VECTOR
RETURN
INITIALIZATION
NENTRY = 2
INITIALIZATION PINDEX = 0
RETURN
NENTRY = 3
PINDEX COMPUTATION
CALCULATE PINDEX =
$\left[\sum_{i=1}^{N} WGTV(I) \times YV(I)^2\right]^{\frac{1}{2}}$
RETURN

Fig. 4.7.13 PINDX flow diagram.

INPUT DATA

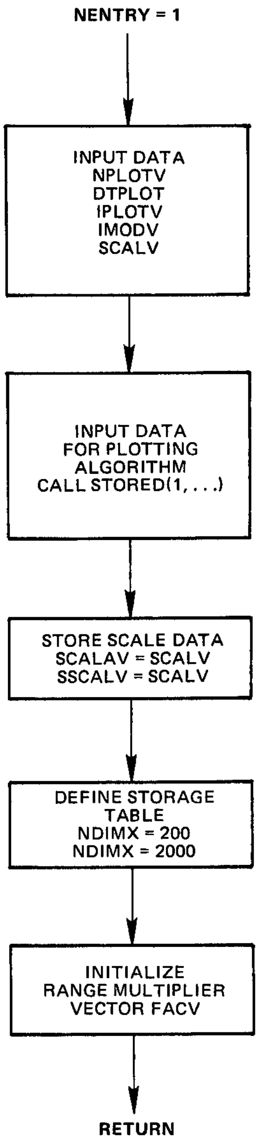
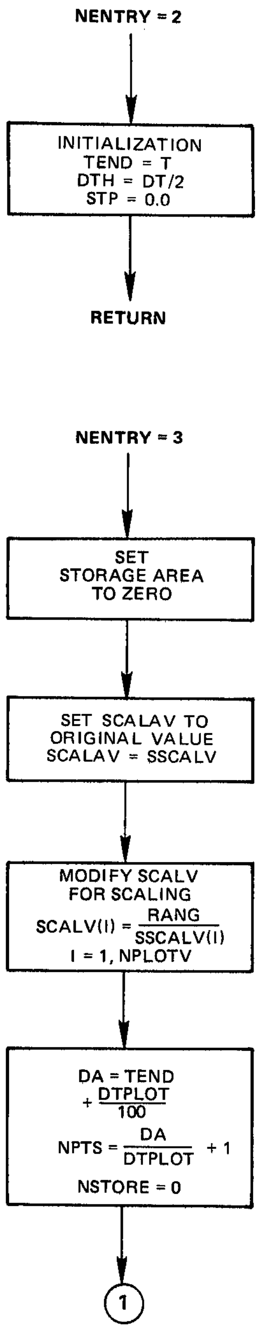


Fig. 4.7.14 PLRT flow diagram.



INITIALIZATION

START OF PLOT RUN

DEFINE AND PROTECT THE
DATA SET

SIZE X STORAGE

Fig. 4.7.14 Cont.

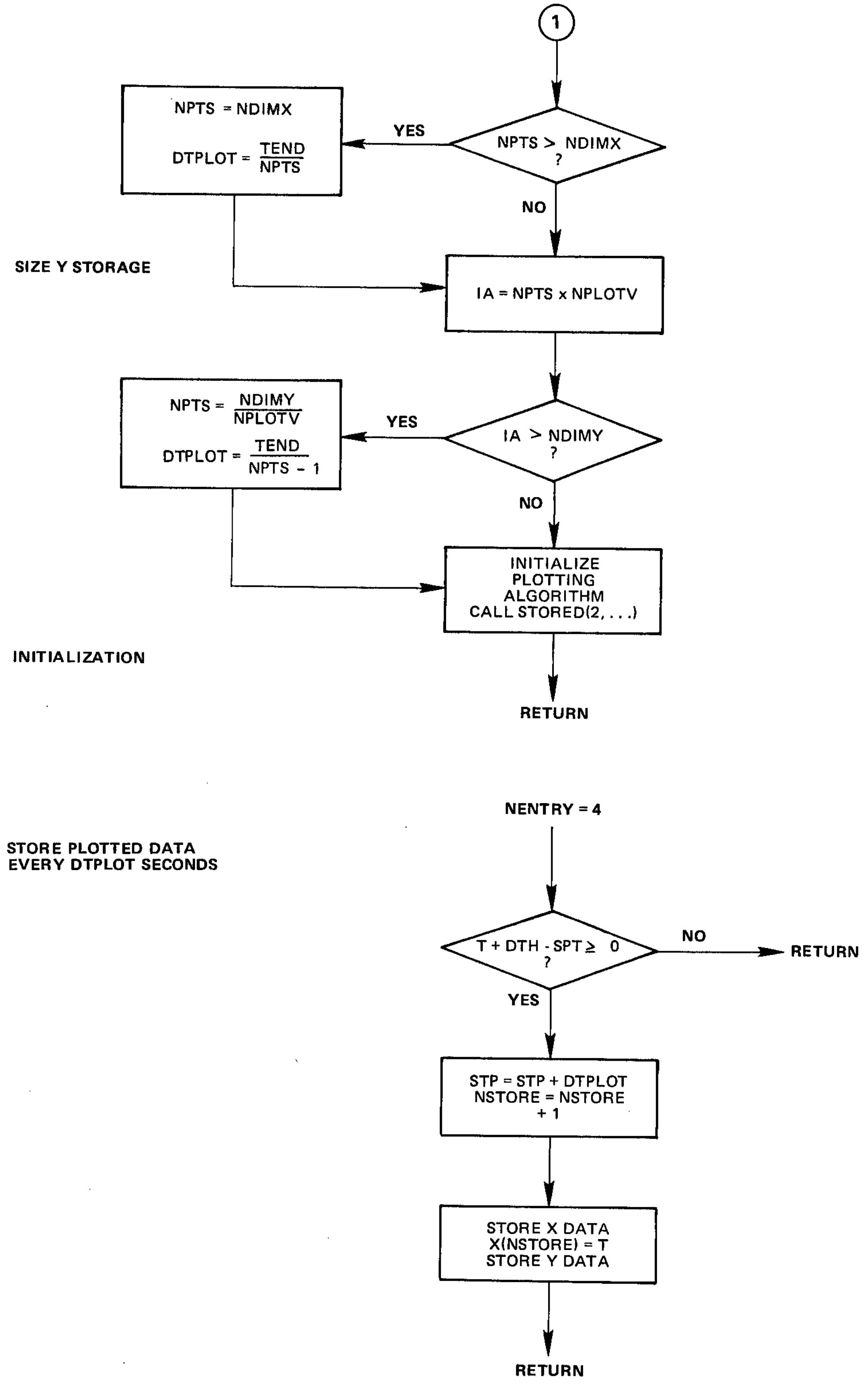


Fig. 4.7.14 Cont.

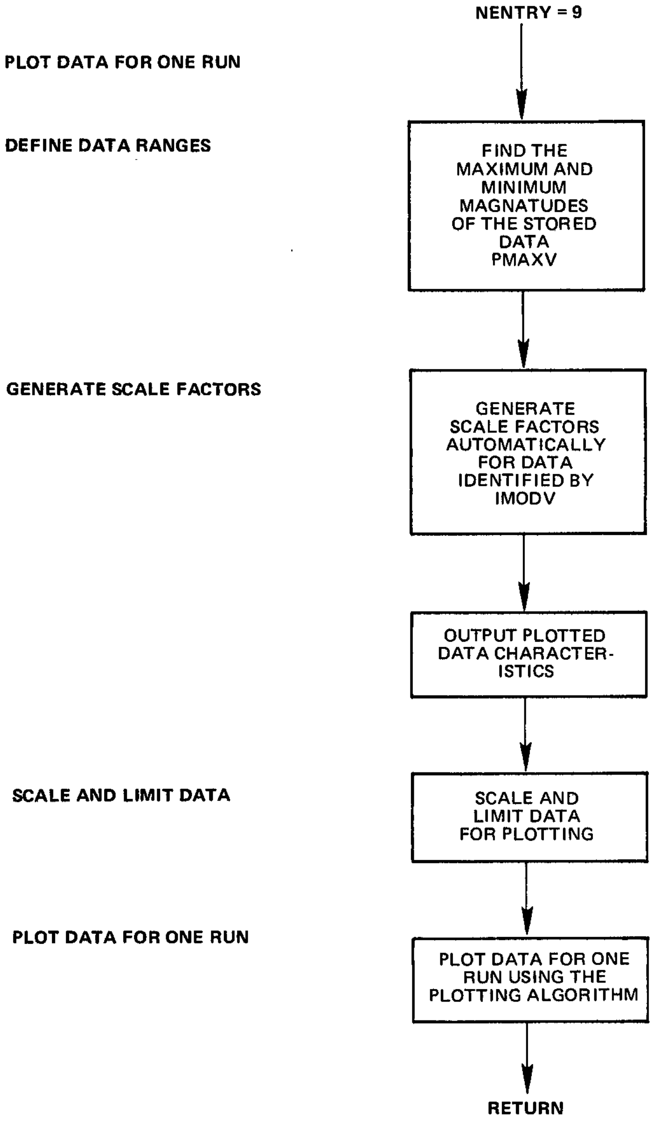

NENTRY = 9
PLOT DATA FOR ONE RUN
DEFINE DATA RANGES
FIND THE MAXIMUM AND MINIMUM MAGNATUDES OF THE STORED DATA PMAXV
GENERATE SCALE FACTORS
GENERATE SCALE FACTORS AUTOMATICALLY FOR DATA IDENTIFIED BY IMODV
OUTPUT PLOTTED DATA CHARACTER-ISTICS
SCALE AND LIMIT DATA
SCALE AND LIMIT DATA FOR PLOTTING
PLOT DATA FOR ONE RUN
PLOT DATA FOR ONE RUN USING THE PLOTTING ALGORITHM
RETURN

Fig. 4.7.14 Cont.

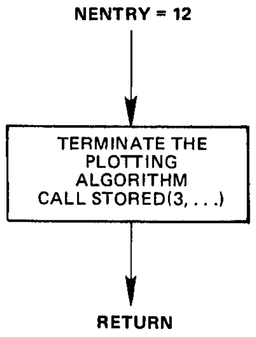


Fig. 4.7.14 Cont.

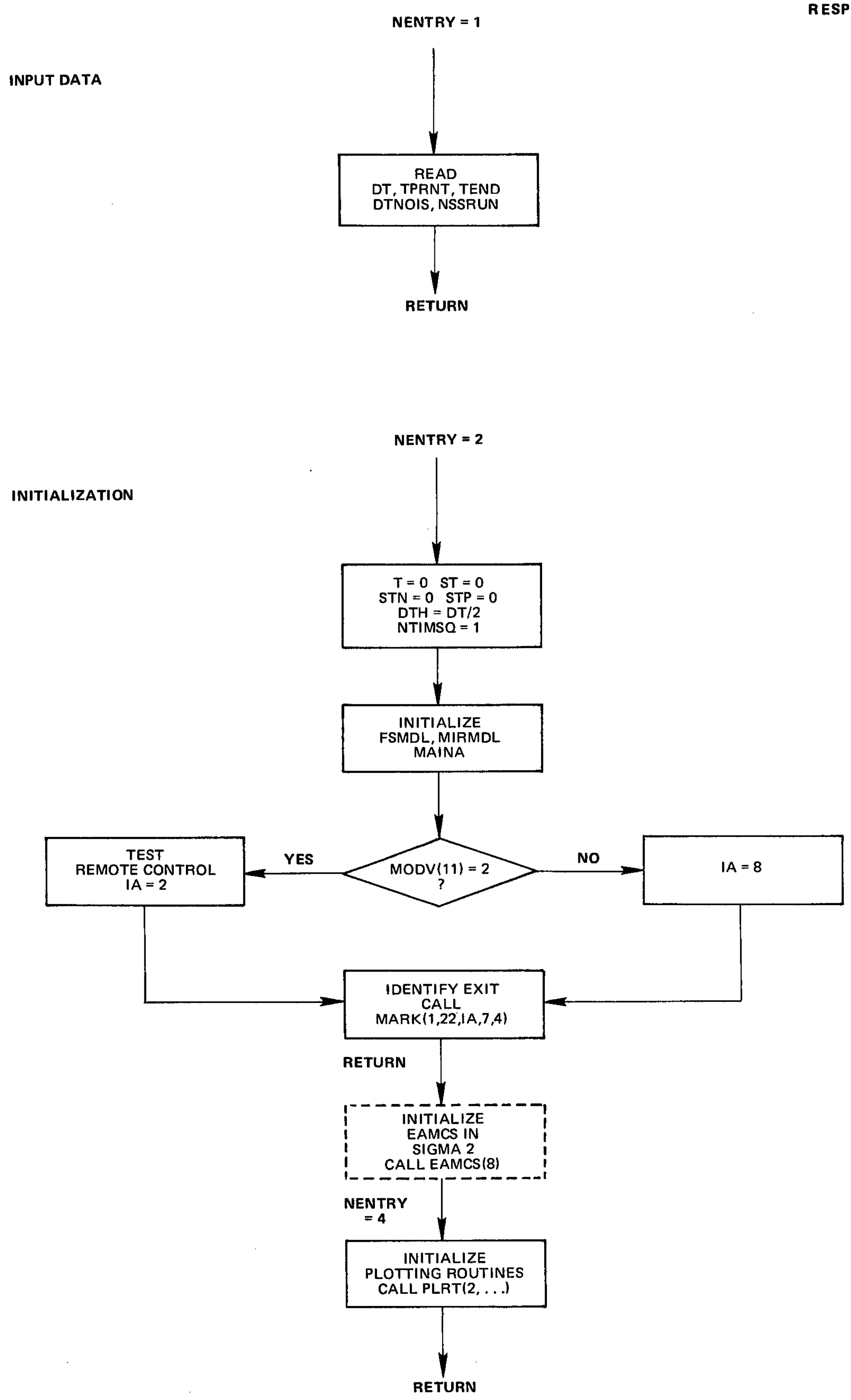


Fig. 4.7.15 RESPON flow diagram.

RESPON 2/4

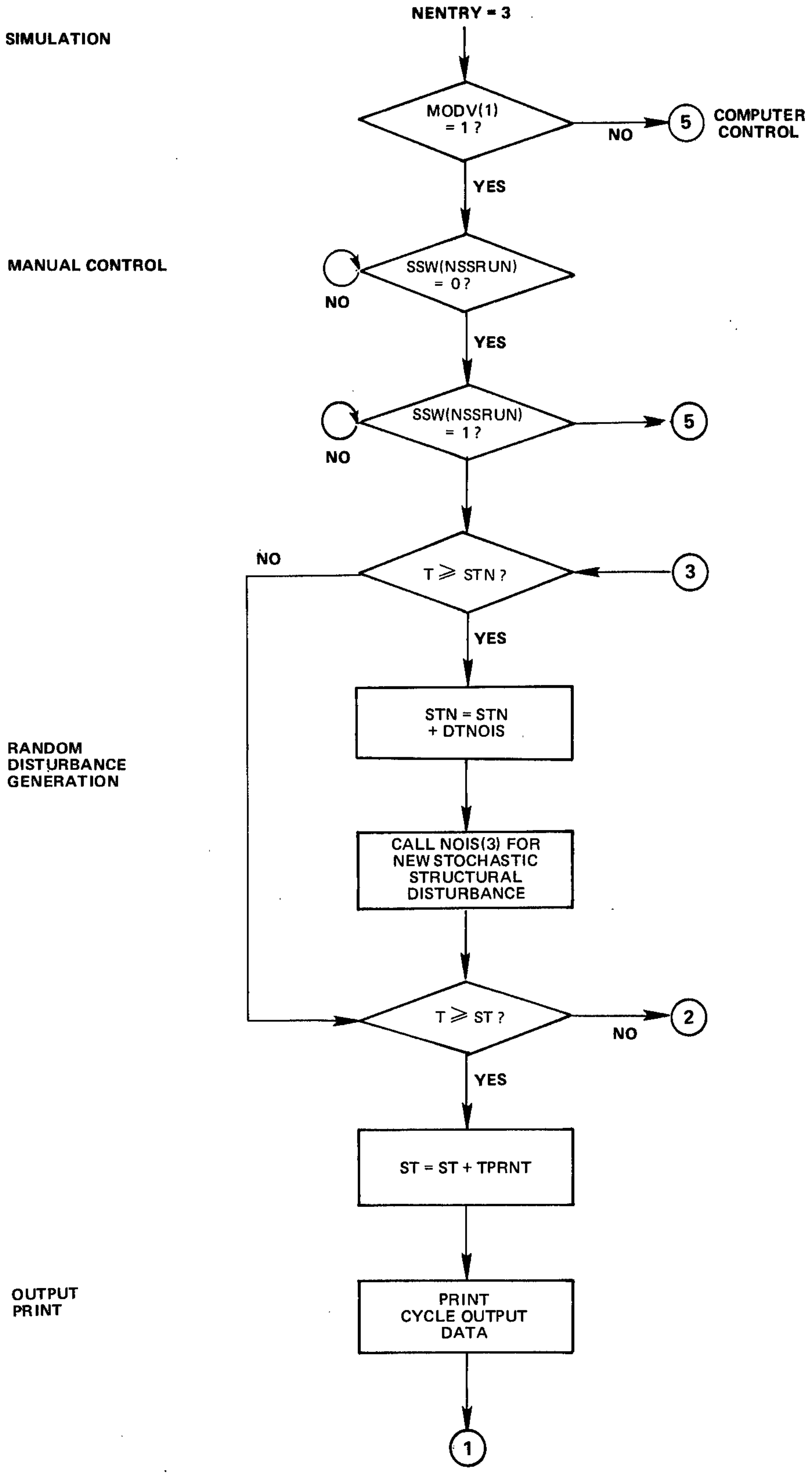


Fig. 4.7.15 Cont.

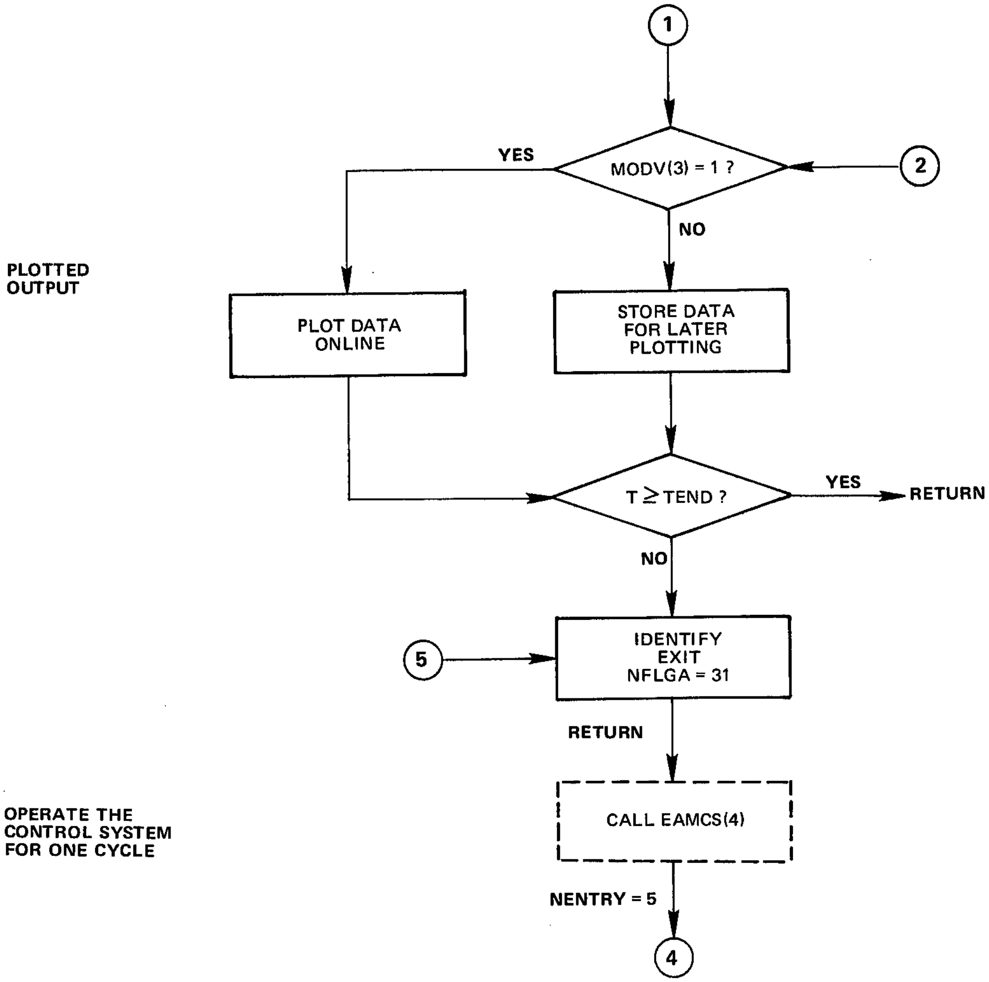


Fig. 4.7.15 Cont.

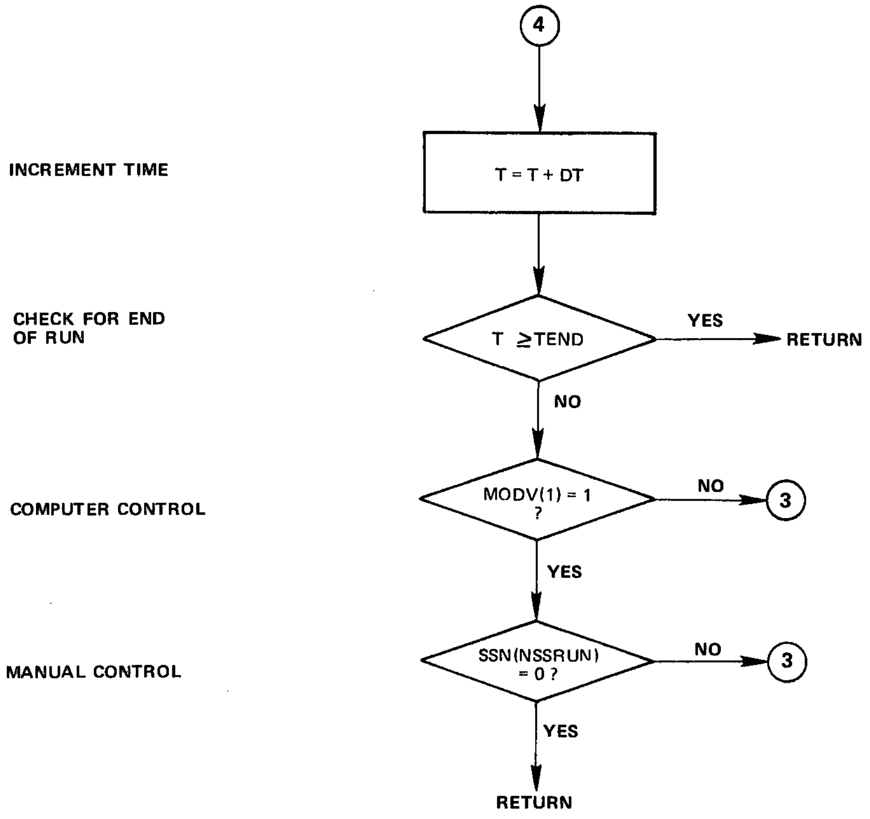


Fig. 4.7.15 Cont.

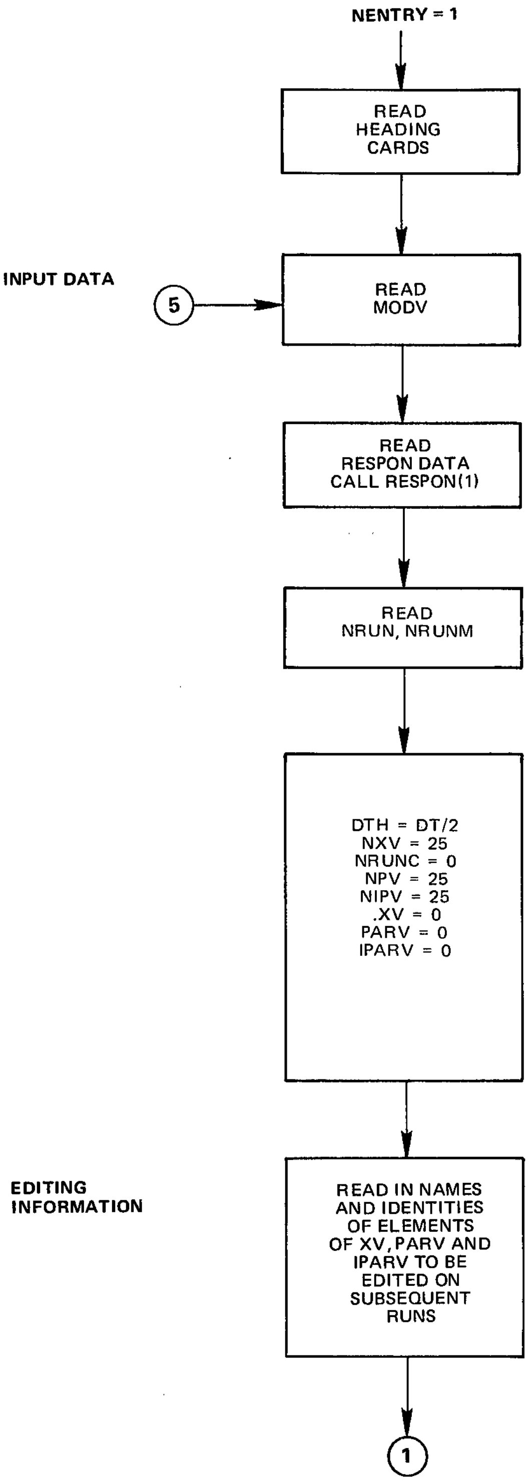


Fig. 4.7.16 SIMSYS flow diagram.

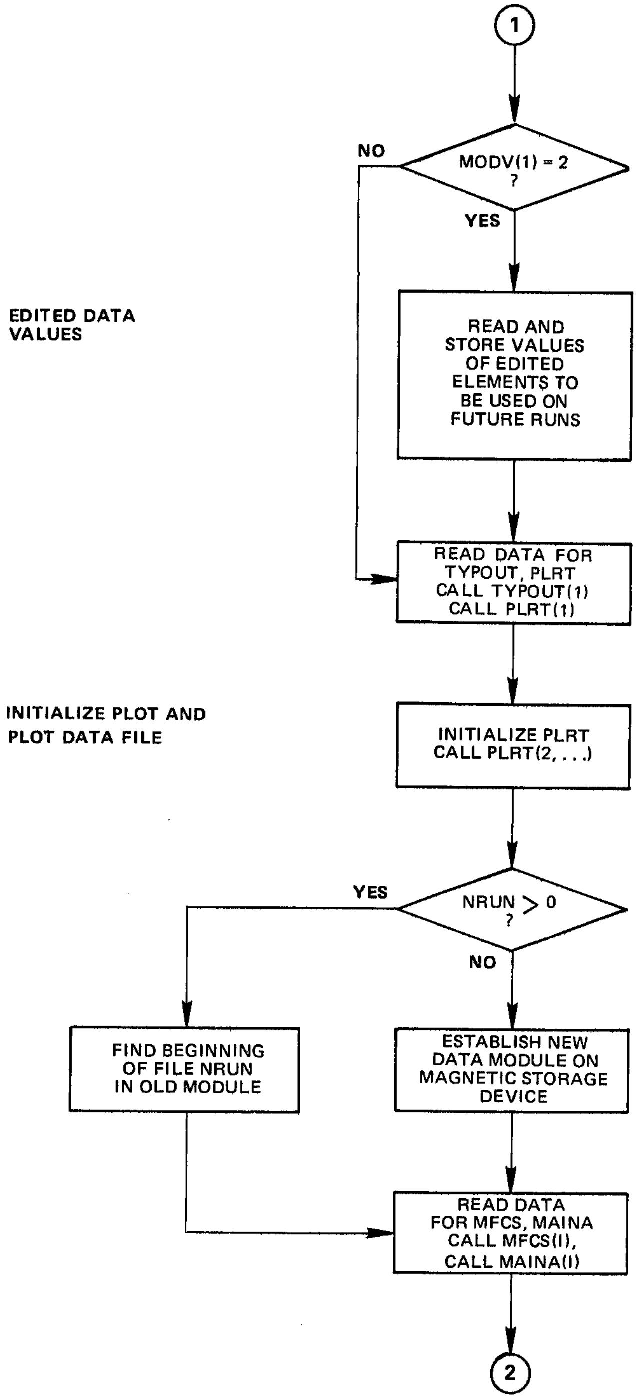

1
MODV(1) = 2 ?
NO
YES
EDITED DATA VALUES
READ AND STORE VALUES OF EDITED ELEMENTS TO BE USED ON FUTURE RUNS
READ DATA FOR TYPOUT, PLRT CALL TYPOUT(1) CALL PLRT(1)
INITIALIZE PLOT AND PLOT DATA FILE
INITIALIZE PLRT CALL PLRT(2, . . .)
NRUN > 0 ?
YES
NO
FIND BEGINNING OF FILE NRUN IN OLD MODULE
ESTABLISH NEW DATA MODULE ON MAGNETIC STORAGE DEVICE
READ DATA FOR MFCS, MAINA CALL MFCS(I), CALL MAINA(I)
2

Fig. 4.7.16 Cont.

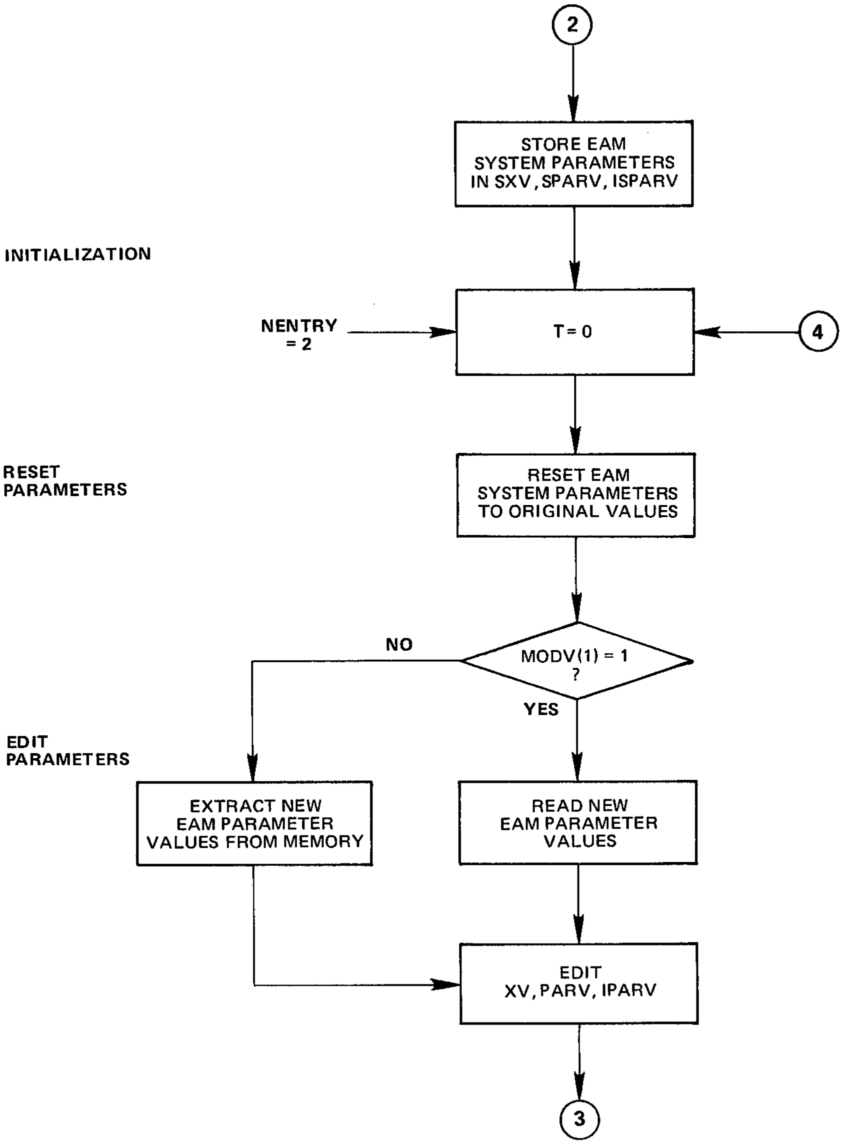

2
STORE EAM SYSTEM PARAMETERS IN SXV, SPARV, ISPARV
INITIALIZATION
NENTRY = 2
T = 0
4
RESET PARAMETERS
RESET EAM SYSTEM PARAMETERS TO ORIGINAL VALUES
NO
MODV(1) = 1 ?
YES
EDIT PARAMETERS
EXTRACT NEW EAM PARAMETER VALUES FROM MEMORY
READ NEW EAM PARAMETER VALUES
EDIT XV, PARV, IPARV
3

Fig. 4.7.16 Cont.

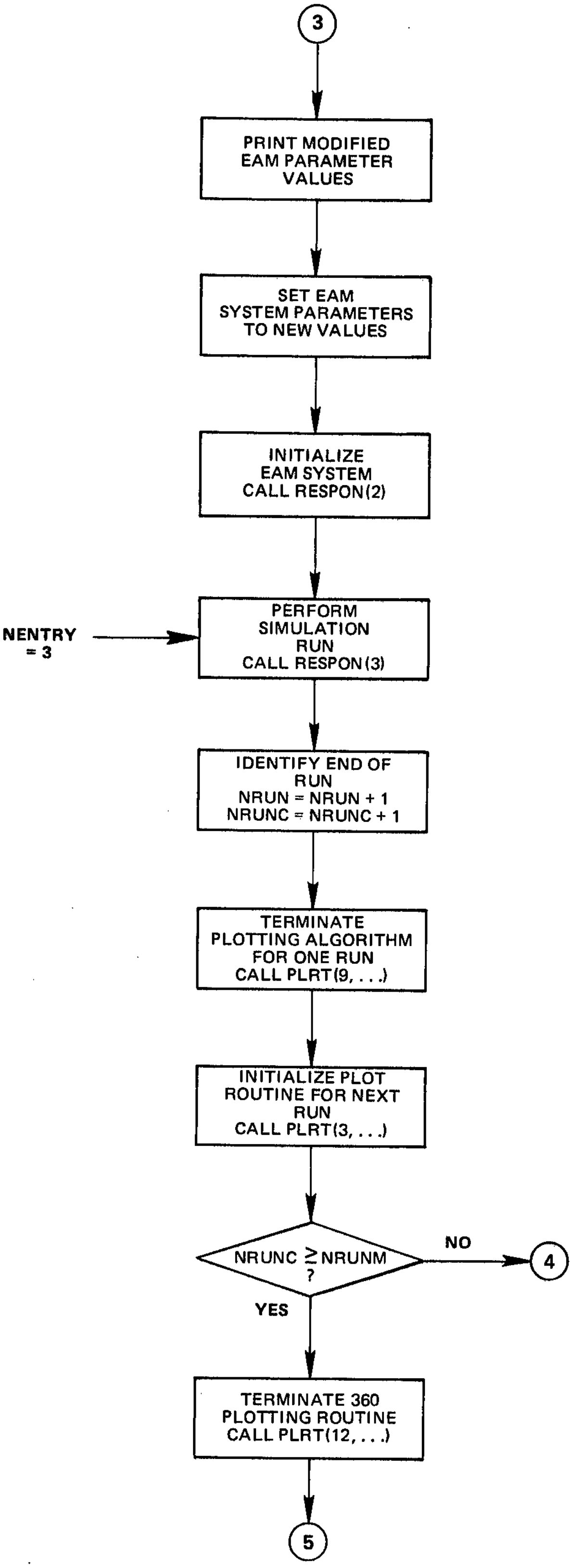

3
PRINT MODIFIED EAM PARAMETER VALUES
SET EAM SYSTEM PARAMETERS TO NEW VALUES
INITIALIZE EAM SYSTEM CALL RESPON(2)
NENTRY = 3
PERFORM SIMULATION RUN CALL RESPON(3)
IDENTIFY END OF RUN NRUN = NRUN + 1 NRUNC = NRUNC + 1
TERMINATE PLOTTING ALGORITHM FOR ONE RUN CALL PLRT(9, . . .)
INITIALIZE PLOT ROUTINE FOR NEXT RUN CALL PLRT(3, . . .)
NRUNC ≥ NRUNM ?
NO
4
YES
TERMINATE 360 PLOTTING ROUTINE CALL PLRT(12, . . .)
5

Fig. 4.7.16 Cont.

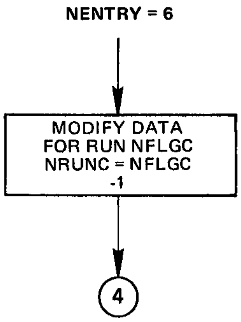


Fig. 4.7.16 Cont.

STORED 1/2

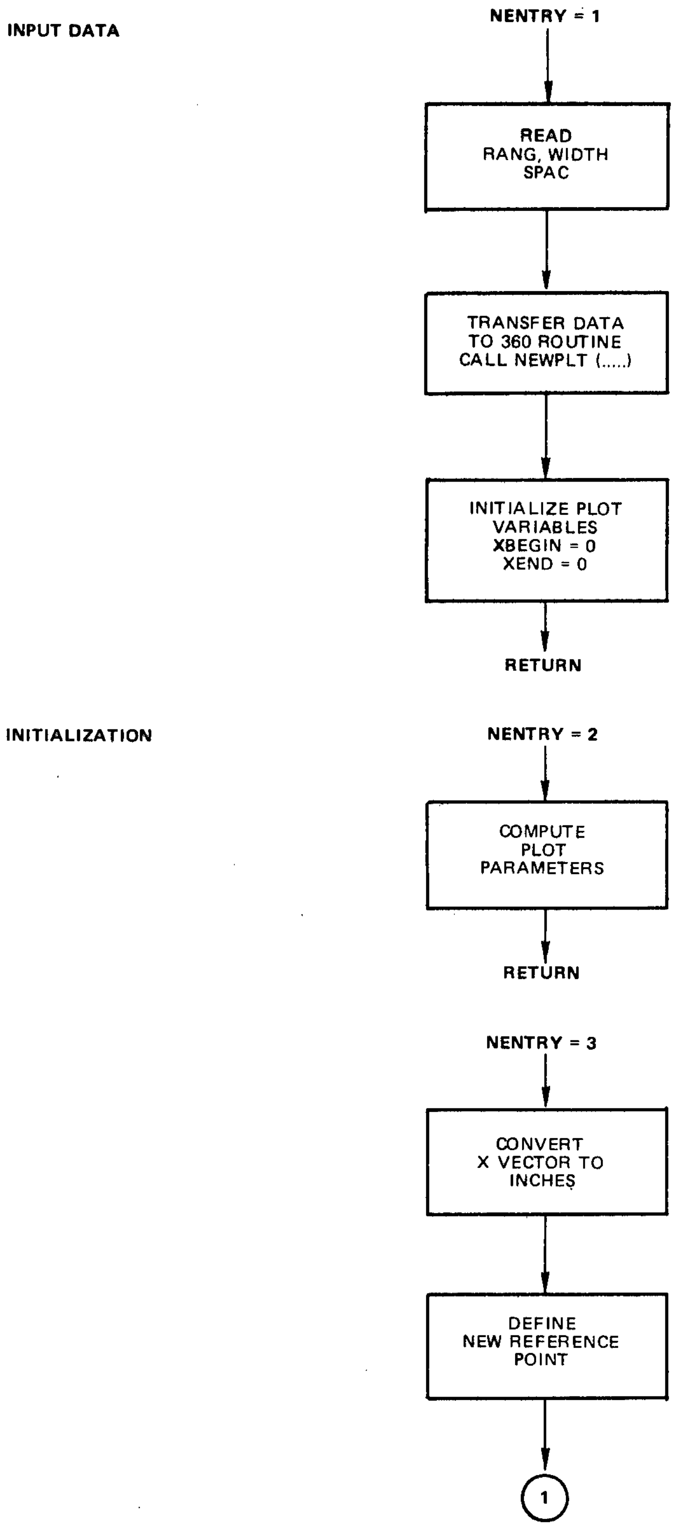


Fig. 4.7.17 STORED flow diagram.

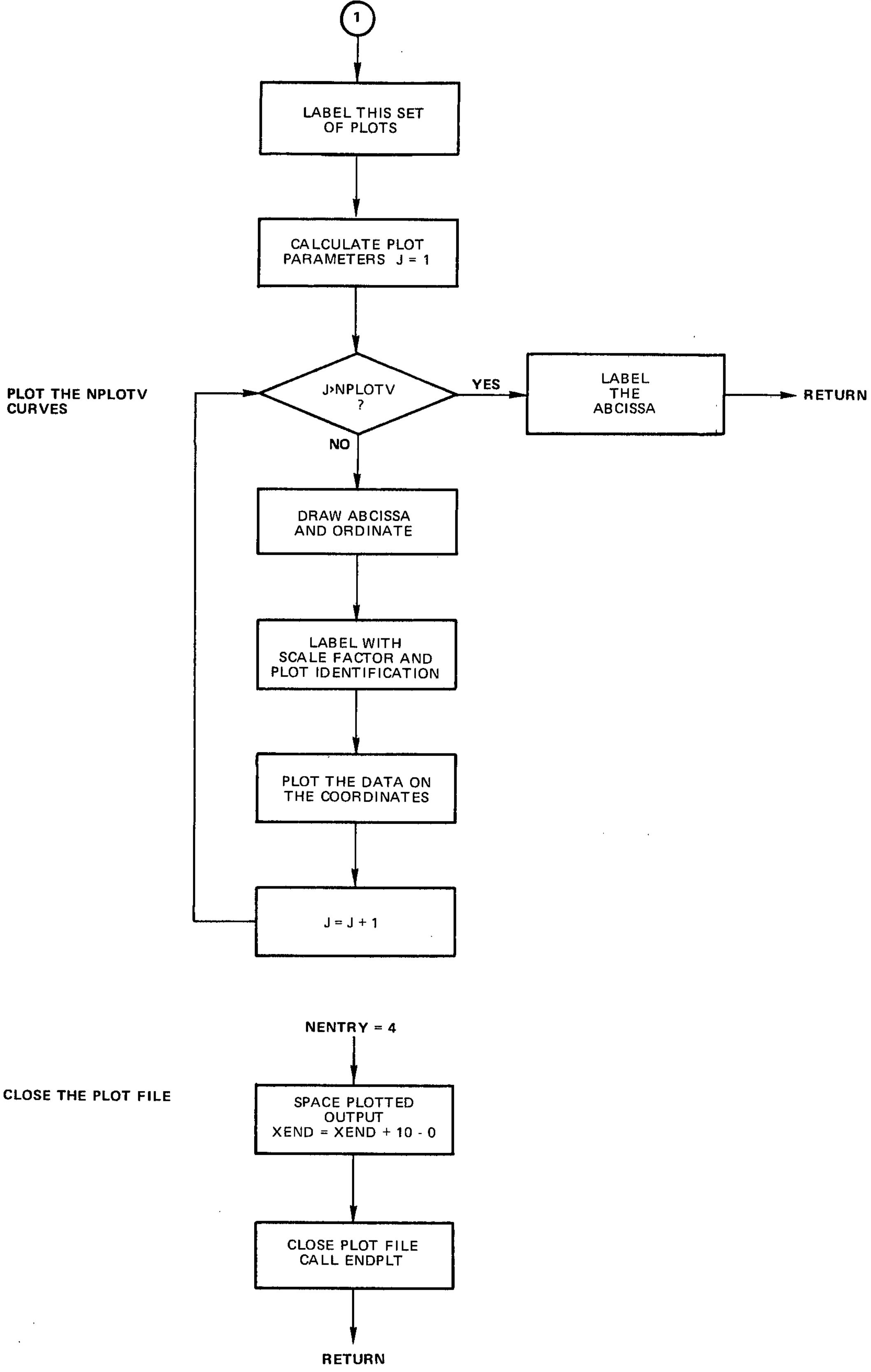

1
LABEL THIS SET OF PLOTS
CALCULATE PLOT PARAMETERS J = 1
PLOT THE NPLOTV CURVES
J›NPLOTV ?
YES
NO
LABEL THE ABCISSA
RETURN
DRAW ABCISSA AND ORDINATE
LABEL WITH SCALE FACTOR AND PLOT IDENTIFICATION
PLOT THE DATA ON THE COORDINATES
J = J + 1
NENTRY = 4
CLOSE THE PLOT FILE
SPACE PLOTTED OUTPUT XEND = XEND + 10 - 0
CLOSE PLOT FILE CALL ENDPLT
RETURN

Fig. 4.7.17 Cont.

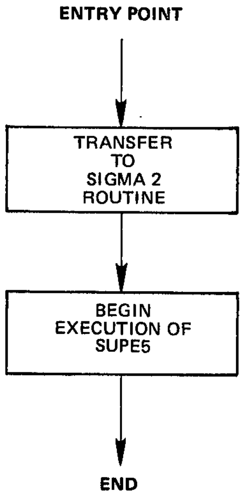


Fig. 4.7.18 SUPE2 flow diagram.

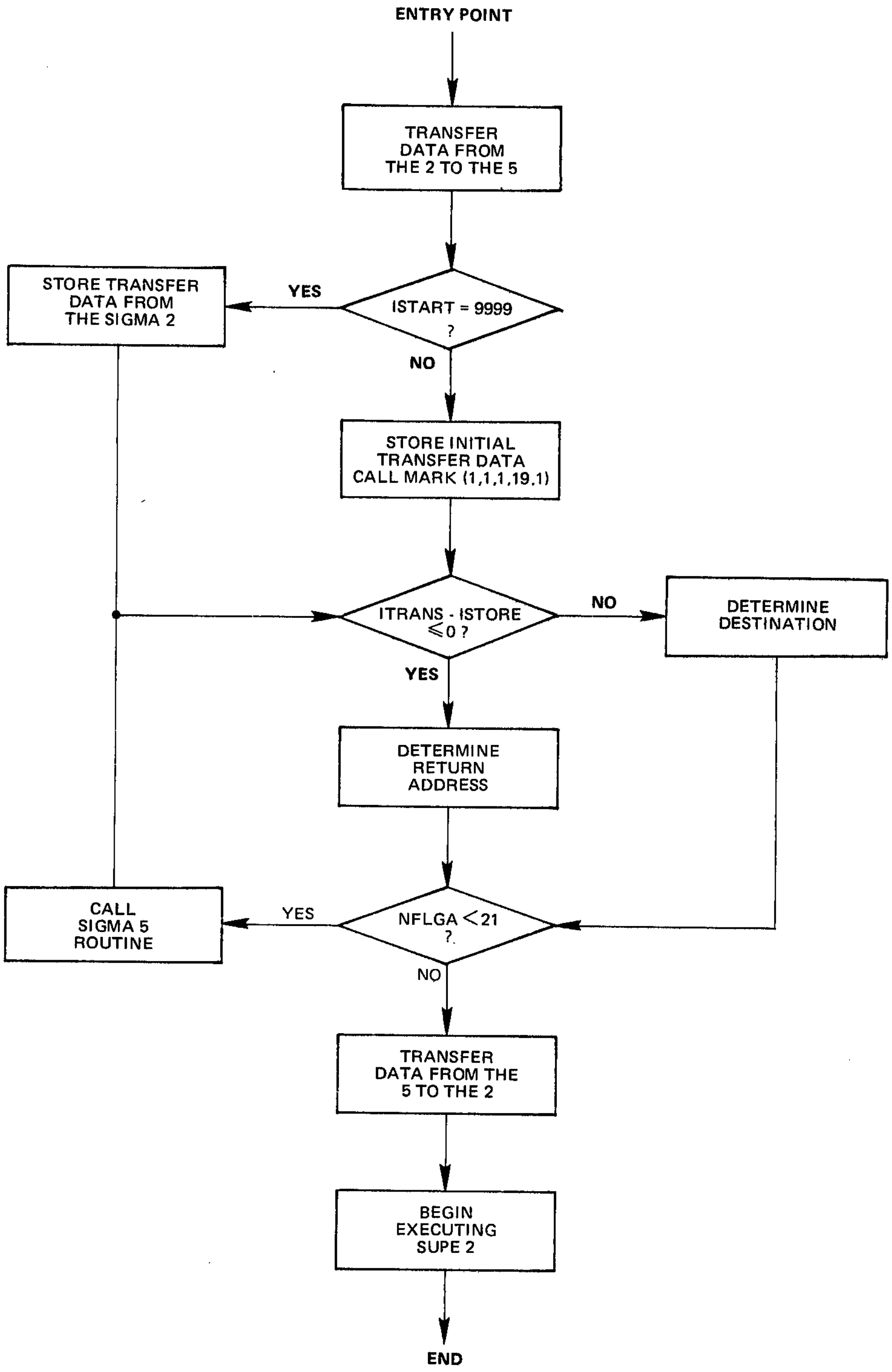


Fig. 4.7.19 SUPE5 flow diagram.

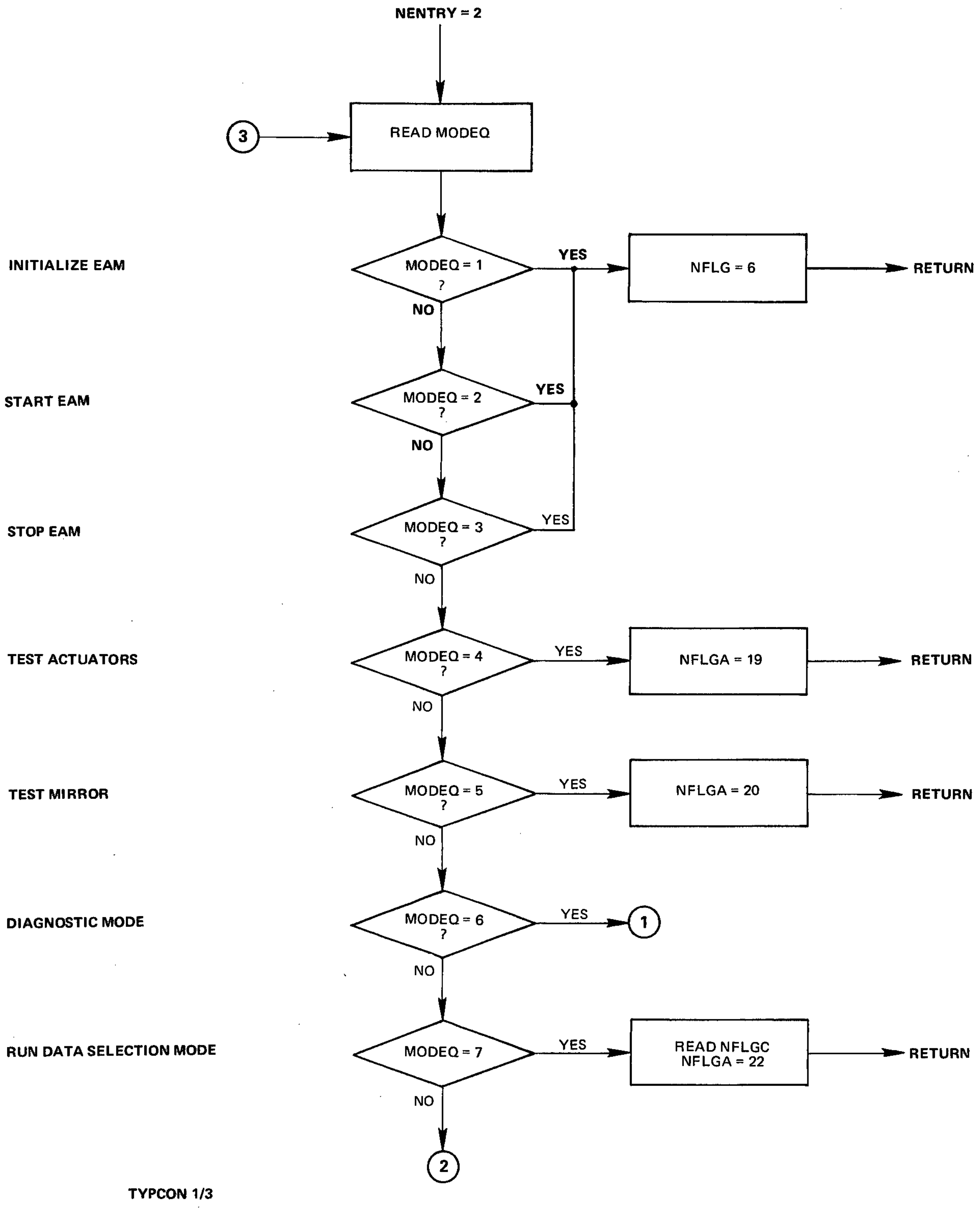


Fig. 4.7.20 TYPCON flow diagram.

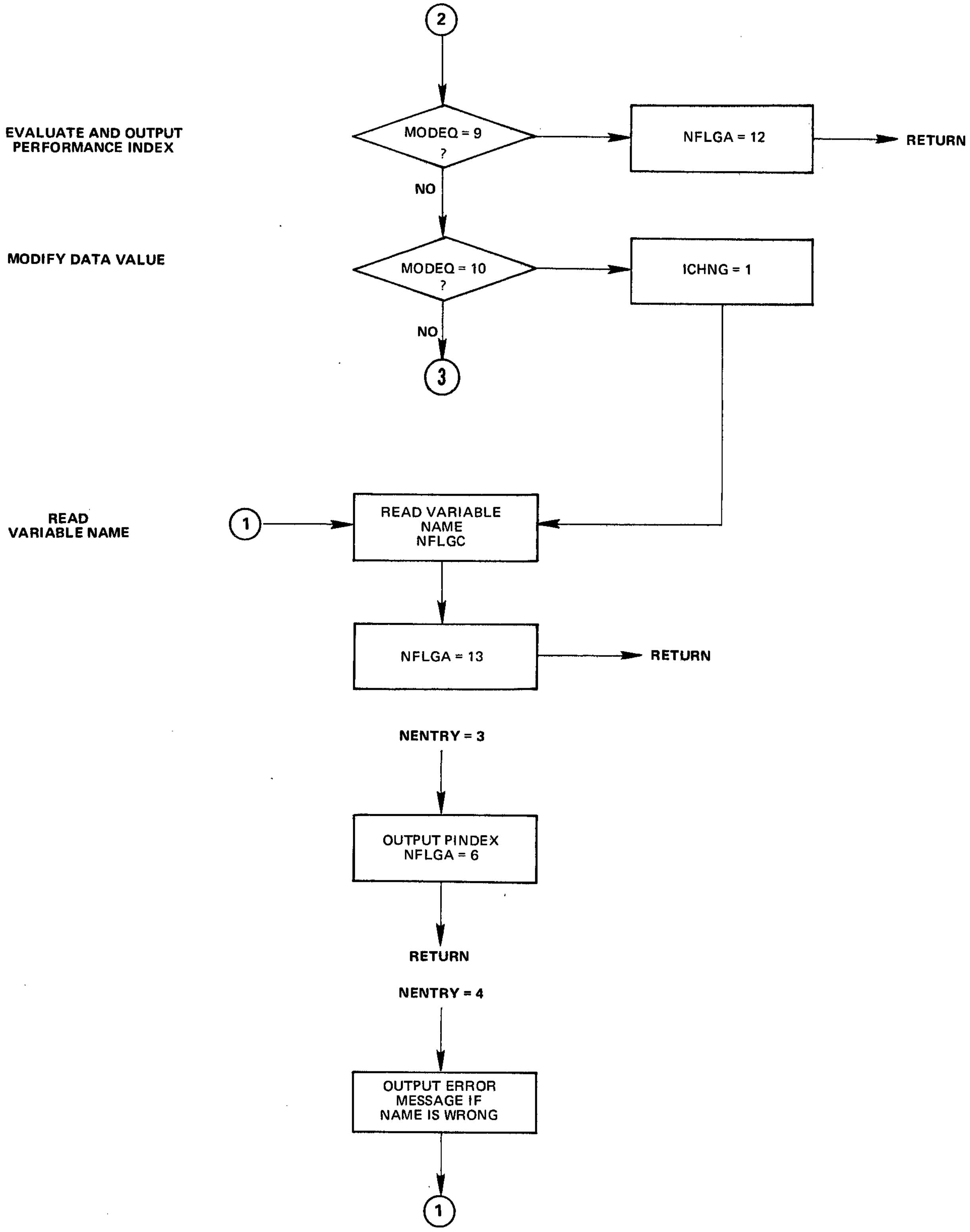


Fig. 4.7.20 Cont.

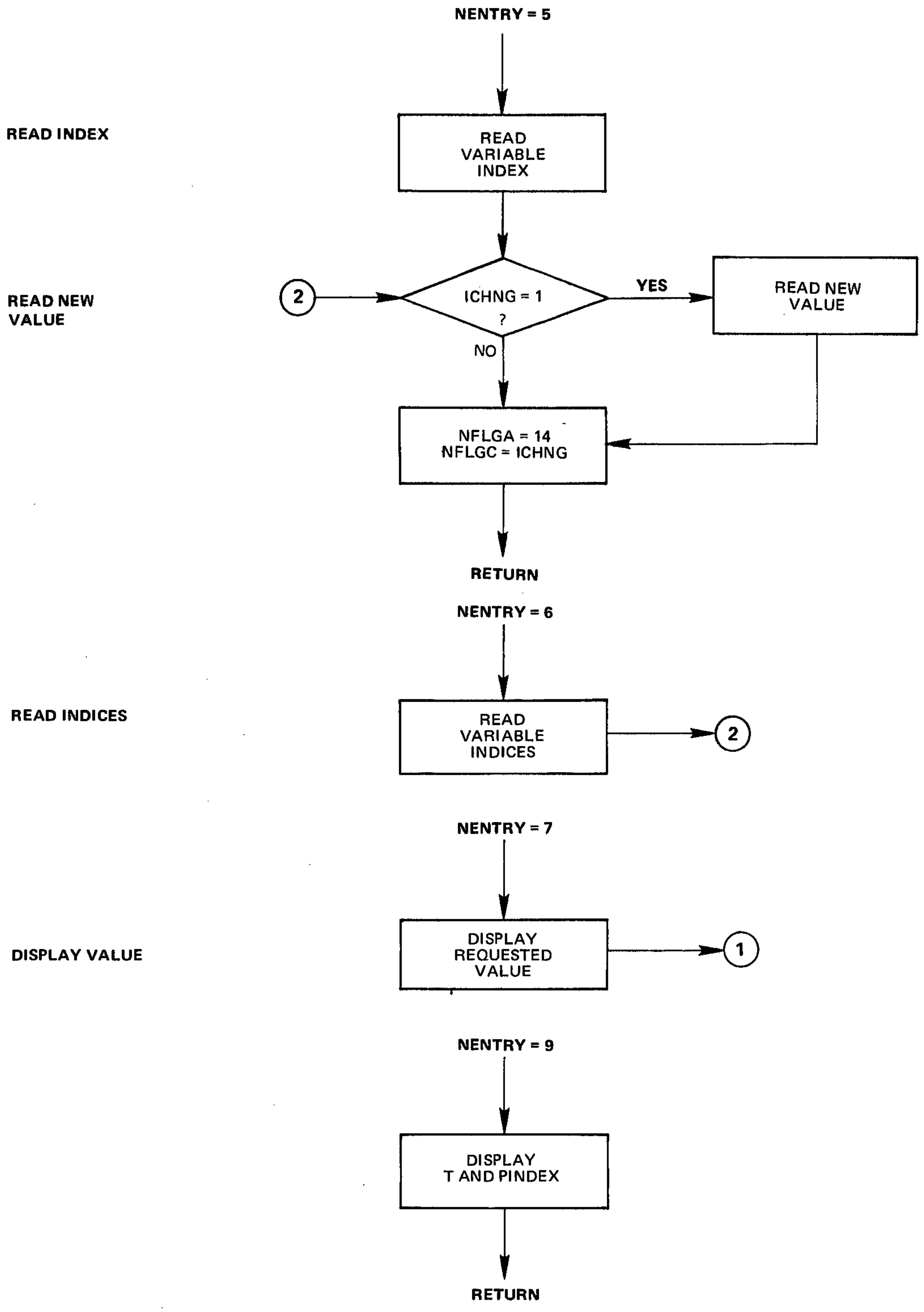


Fig. 4.7.20 Cont.

4.7.20 TYPCON: Remote Terminal Control Software

TYPCON provides the software required to transfer information to and from the remote terminal.

CHAPTER 5

EXPERIMENTAL ACTIVE MIRROR INPUT DATA

5.1 Introduction

Data for the EAM software is read in card format by the Sigma 5 card reader. This procedure was adopted to minimize the use of the rather limited input-output capability of the Sigma 2 computer.

Most of the input data operations are performed by subroutine members of the Input-Output Operations Package (IOP) which is described in Appendix B. Utilization of IOP subroutines results in large savings in core memory by reducing compiler generated in line code compared to that produced by READ and WRITE statements.

Considerable memory space is saved and a high level of convenience achieved by combining data heading cards with the data deck. This obviates the need for format statements and simplifies the identification of the data elements in the data deck.

Fixed point data is generally read in a 7I10 Format while floating point data is read in a 7E10.0 Format which automatically identifies the decimal point location. Single dimension arrays are read in transposed form while two-dimensional arrays are read in row by row.

Data is never read in columns 73-80 to allow space for data deck identification letters and card sequence numbers.

5.2 Input Data Deck Description

The following sections provide a sequential description of the input data deck. Heading cards are indicated by their contents, e.g., NHEADING. Headings for numerical data are read in 7(2X, A8) format. Numerical data is indicated by its input format, e.g., (I10), or (E10.0). If the input data does not correspond in name to the heading card, the name is included in the format description, e.g., (N, I10). A listing of the input data is shown in Fig. 5.2.1.

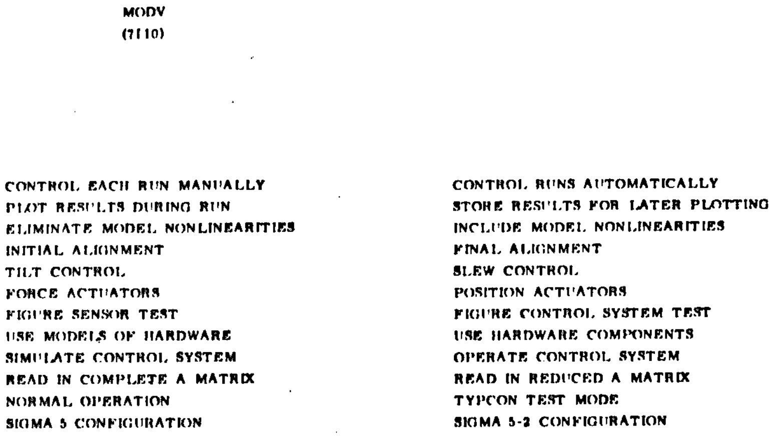
5.2.1 Output Data Heading

The Sigma 5 reads a heading card NHEADING and an integer N which defines the number of heading cards to be read in and printed in A format. The card defining the value of N is followed by the heading cards as indicated in Fig. 5.2.1.

```
NHEADING
    (N, I10)
            N Heading cards (18A4)
```

5.2.2 Operating Modes

The operating modes of the system are read in as a one-dimensional array. The computer reads a heading card followed by the MODV array values followed by a set of cards which contain the mode identification names in 2(18A4) format. The computer reads



```
          MODV
          (7I10)



CONTROL EACH RUN MANUALLY                  CONTROL RUNS AUTOMATICALLY
PLOT RESULTS DURING RUN                    STORE RESULTS FOR LATER PLOTTING
ELIMINATE MODEL NONLINEARITIES             INCLUDE MODEL NONLINEARITIES
INITIAL ALIGNMENT                          FINAL ALIGNMENT
TILT CONTROL                               SLEW CONTROL
FORCE ACTUATORS                            POSITION ACTUATORS
FIGURE SENSOR TEST                         FIGURE CONTROL SYSTEM TEST
USE MODELS OF HARDWARE                     USE HARDWARE COMPONENTS
SIMULATE CONTROL SYSTEM                    OPERATE CONTROL SYSTEM
READ IN COMPLETE A MATRIX                  READ IN REDUCED A MATRIX
NORMAL OPERATION                           TYPCON TEST MODE
SIGMA 5 CONFIGURATION                      SIGMA 5-2 CONFIGURATION
```

```
NHEADING
      44

*       *   ********   **********    *******
**     **  *           *           *       *
* *   * *   ********   *****       *
*  * *  *           *  *           *
*   *   *  *        *  *           *       *
*       *   ********   *           ********

*       *  *  ********   ********    *******    ********
**     **  *  *       *  *       *  *       *  *       *
* *   * *  *  ********   ********   *       *  ********
*  * *  *  *  *     *    *     *    *       *  *     *
*   *   *  *  *      *   *      *   *       *  *      *
*       *  *  *       *  *       *   *******   *       *

*********  *   *******   *       *  ********   *********
*          *  *          *       *  *       *  *
*****      *  *          *       *  ********   *****
*          *  *     ***  *       *  *    *     *
*          *  *       *  *       *  *     *    *
*          *   *******    *******   *      *   *********

 *******   *******   **     *  *********  ********   *******   *
*       *  *       *  * *    *      *     *       *  *       *  *
*          *       *  *  *   *      *     ********   *       *  *
*          *       *  *   *  *      *     *    *     *       *  *
*       *  *       *  *    * *      *     *     *    *       *  *
 *******    *******   *     **      *     *      *    *******   ******

 *******  *       *   *******   *********  *********  *       *
*          *     *   *              *      *          **     **
 *******     *   *     *******      *      *****      * *   * *
        *     * *             *     *      *          *  * *  *
*       *      *      *       *     *      *          *   *   *
 *******       *       *******      *      *********  *       *

DEVELOPED BY THE CHARLES STARK DRAPER LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASSACHUSETTS 02139
     MODV
        2         2         1         2         1         1         2
        1         1         1         1         1
CONTROL EACH RUN MANUALLY             CONTROL RUNS AUTOMATICALLY
PLOT RESULTS DURING RUN               STORE RESULTS FOR LATER PLOTTING
ELIMINATE MODEL NONLINEARITIES        INCLUDE MODEL NONLINEARITIES
INITIAL ALIGNMENT                     FINAL ALIGNMENT
TILT CONTROL                          SLEW CONTROL
FORCE ACTUATORS                       POSITION ACTUATORS
FIGURE SENSOR TEST                    FIGURE CONTROL SYSTEM TEST
USE MODELS OF HARDWARE                USE HARDWARE COMPONENTS
SIMULATE CONTROL SYSTEM               OPERATE CONTROL SYSTEM
READ IN THE COMPLETE A MATRIX         READ IN THE REDUCED A MATRIX
NORMAL OPERATION                      TYPCON TEST MODE
```

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Fig. 5.2.1 Input data deck.

```
SIGMA 5 CONFIGURATION                        SIGMA 5-2 CONFIGURATION
          DT        TPRNT        TEND      DTNOIS
 0.100       6.50        200.0        10000.0
      NSSRUN
           1
        NRUN        NRUNM
     1104710            1
        NCXV         NCPV         NICPV
           1            1             1
          X1
          36
        GAIN           DT          TEND      FSTFLT
           1            2             3           4
         IP1
          11
         CXM

         CPM
 -.050
        CIPM

       NTYPE
           6
      NPLOTV
          24
      DTPLOT
   6.50
      IPLOTV
           1            4            5           6           7           8           9
          10           11           12          13          14          15          16
          17           18           19          20          21          22          23
          24           25           26
       IMODV
           2            2            2           2           2           2           2
           2            2            2           2           2           2           2
           2            2            2           2           2           2           2
           2            2            2
       SCALV
 1.0          1.0          1.0         1.0         1.0         1.0          1.0
 1.0          1.0          1.0         1.0         1.0         1.0          1.0
 1.0          1.0          1.0         1.0         1.0         1.0          1.0
 1.0          1.0          1.0
      NSNSWT        NTYPI        NTYPO      NPUNCH        NMAG
           1            5            6           6           6
           N           NR
          16            7
          AM
    12.02290     10.12680     10.75020     5.52466    -2.41734     3.20453     5.52466
    10.12680     10.75020      6.38214     6.56174    -2.15830    -2.15830     6.56174
     6.38214      9.83788
    10.12680     86.33018     38.73888    10.12680   -21.20290    -6.26523    -2.41734
   -21.20290     -6.26523     53.41199    53.41199   -22.75899    -8.63721    -8.63721
   -22.75899      7.31642
    10.75020     38.73888     26.41588    10.75020    -6.26523     2.50271     3.20453
    -6.26523      2.50271     25.24458    25.24458    -8.18677    -2.07520    -2.07520
    -8.18677     11.23680
     5.52466     10.12680     10.75020    12.02290    10.12680    10.75020     5.52466
  -2.41734    3.20453      6.56174     6.38214     6.38214     6.56174     -2.1583
   -2.41734   9.83788
    -2.41734    -21.20290     -6.26523    10.12680    86.33018    38.73888    10.12680
```

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Fig. 5.2.1 Cont.

```
 -21.20290   -6.26523   -8.63721  -22.75899   53.41199   53.41199  -22.75899
  -8.63721    7.31642
   3.20453   -6.26523    2.50271   10.75020   38.73888   26.41588   10.75020
  -6.26523    2.50271   -2.07520   -8.18677   25.24458   25.24458   -8.18677
  -2.07520   11.23680
   5.52466   -2.41734    3.20453    5.52466   10.12680   10.75020   12.02290
  10.12680   10.75020   -2.15830   -2.15830    6.56174    6.38214    6.38214
   6.56174    9.83788
  10.12680  -21.20290   -6.26523   -2.41734  -21.20290   -6.26523   10.12680
  86.33018   38.73888  -22.75899   -8.63721   -8.63721  -22.75899   53.41199
  53.41199    7.31642
  10.75020   -6.26523    2.50271    3.20453   -6.26523    2.50271   10.75020
  38.73888   26.41588   -8.18677   -2.07520   -2.07520   -8.18677   25.24458
  25.24458   11.23680
   6.38214   53.41199   25.24458    6.56174   -8.63721   -2.07520   -2.15830
 -22.75899   -8.18677   47.71928   28.99750  -10.87630   -1.90107  -10.87630
 -23.13948    4.33471
   6.56174   53.41199   25.24458    6.38214  -22.75899   -8.18677   -2.15830
  -8.63721   -2.07520   28.99750   47.71928  -23.13948  -10.87630   -1.90107
 -10.87630    4.33471
  -2.15830  -22.75899   -8.18677    6.38214   53.41199   25.24458    6.56174
  -8.63721   -2.07520  -10.87630  -23.13948   47.71928   28.99750  -10.87630
  -1.90107    4.33471
  -2.15830   -8.63721   -2.07520    6.56174   53.41199   25.24458    6.38214
 -22.75899   -8.18677   -1.90107  -10.87630   28.99750   47.71928  -23.13948
 -10.87630    4.33471
   6.56174   -8.63721   -2.07520   -2.15830  -22.75899   -8.18677    6.38214
  53.41199   25.24458  -10.87630   -1.90107  -10.87630  -23.13948   47.71928
  28.99750    4.33471
   6.38214  -22.75899   -8.18677   -2.15830   -8.63721   -2.07520    6.56174
  53.41199   25.24458  -23.13948  -10.87630   -1.90107  -10.87630   28.99750
  47.71928    4.33471
   9.83788    7.31642   11.23680    9.83788    7.31642   11.23680    9.83788
   7.31642   11.23680    4.33471    4.33471    4.33471    4.33471    4.33471
   4.33471   15.99379
    ASCALE     AIMSCL
 0.0931      10.00
    FSCALE
  1.0
    XFSV



    YFSV



   PSCALE
1.0
   LACTV
         0          1          1                     1          1
         1          1
                    1
   ASCALV
1.0        1.0        1.0        1.0        1.0        1.0        1.0
   MODOP
         1
   NMFASA
```

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Fig. 5.2.1 Cont.

```
         1
      DACT
0.10
    NMFASE
         1
      DACT
0.10
    NTIMSQ     NWAIT      NPOS     NMINT     NMFAS      NTYO
         1         1         1         3         1         1
        DT       DTE  GAINV(1)       QGA       QGB     UFMAX
0.100     0.00001   -0.250    1.0       1.0       20.0
    SIGLIM     SLPMN
1000.0    0.0
     MSEQV
         2        11         4        12         6         5        13
         7        14         8         9        15         1        10
         3        15
    FSNSIG    FSTFLT
 0.0      0.0
     IRAND     IPLOT
         1         2
     TACTV

       AMM
  12.02290  10.12680  10.75020   5.52466  -2.41734   3.20453   5.52466
  10.12680  10.75020   6.38214   6.56174  -2.15830  -2.15830   6.56174
   6.38214   9.83788
  10.12680  86.33018  38.73888  10.12680 -21.20290  -6.26523  -2.41734
 -21.20290  -6.26523  53.41199  53.41199 -22.75899  -8.63721  -8.63721
 -22.75899   7.31642
  10.75020  38.73888  26.41588  10.75020  -6.26523   2.50271   3.20453
  -6.26523   2.50271  25.24458  25.24458  -8.18677  -2.07520  -2.07520
  -8.18677  11.23680
   5.52466  10.12680  10.75020  12.02290  10.12680  10.75020   5.52466
  -2.41734   3.20453   6.56174   6.38214   6.38214   6.56174  -2.15830
  -2.15830   9.83788
  -2.41734 -21.20290  -6.26523  10.12680  86.33018  38.73888  10.12680
 -21.20290  -6.26523  -8.63721 -22.75899  53.41199  53.41199 -22.75899
  -8.63721   7.31642
   3.20453  -6.26523   2.50271  10.75020  38.73888  26.41588  10.75020
  -6.26523   2.50271  -2.07520  -8.18677  25.24458  25.24458  -8.18677
  -2.07520  11.23680
   5.52466  -2.41734   3.20453   5.52466  10.12680  10.75020  12.02290
  10.12680  10.75020  -2.15830  -2.15830   6.56174   6.38214   6.38214
   6.56174   9.83788
  10.12680 -21.20290  -6.26523  -2.41734 -21.20290  -6.26523  10.12680
  86.33018  38.73888 -22.75899  -8.63721  -8.63721 -22.75899  53.41199
  53.41199   7.31642
  10.75020  -6.26523   2.50271   3.20453  -6.26523   2.50271  10.75020
  38.73888  26.41588  -8.18677  -2.07520  -2.07520  -8.18677  25.24458
  25.24458  11.23680
   6.38214  53.41199  25.24458   6.56174  -8.63721  -2.07520  -2.15830
 -22.75899  -8.18677  47.71928  28.99750 -10.87630  -1.90107 -10.87630
 -23.13948   4.33471
   6.56174  53.41199  25.24458   6.38214 -22.75899  -8.18677  -2.15830
  -8.63721  -2.07520  28.99750  47.71928 -23.13948 -10.87630  -1.90107
 -10.87630   4.33471
  -2.15830 -22.75899  -8.18677   6.38214  53.41199  25.24458   6.56174
  -8.63721  -2.07520 -10.87630 -23.13948  47.71928  28.99750 -10.87630
  -1.90107   4.33471
```

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Fig. 5.2.1 Cont.

```
  -2.15830  -8.63721  -2.07520   6.56174  53.41199  25.24458   6.38214
 -22.75899  -8.18677  -1.90107 -10.87630  28.99750  47.71928 -23.13948
 -10.87630   4.33471
   6.56174  -8.63721  -2.07520  -2.15830 -22.75899  -8.18677   6.38214
  53.41199  25.24458 -10.87630  -1.90107 -10.87630 -23.13948  47.71928
  28.99750   4.33471
   6.38214 -22.75899  -8.18677  -2.15830  -8.63721  -2.07520   6.56174
  53.41199  25.24458 -23.13948 -10.87630  -1.90107 -10.87630  28.99750
  47.71928   4.33471
   9.83788   7.31642  11.23680   9.83788   7.31642  11.23680   9.83788
   7.31642  11.23680   4.33471   4.33471   4.33471   4.33471   4.33471
   4.33471  15.99079
      XFDV
0.075     0.0       0.075     0.075     0.0       0.075     0.075
 0.0      0.075
 0.0      0.10
    LRFFAV
         1         2         3         4         5         6         7
         8         9
      SMXV


      SMYV


      BSMP      BSDP      DELU
 1.0    -  -1.0      0.10
       NHM       NIM
        10        10
     NTILT    NCTILT
        10        10
     GTILT
-1.0
     NCVEL
        10
      WGTV
 0.0625   0.0625    0.0625   0.0625     0.0625    0.0625    0.0625
 0.0625   0.0625    0.0625   0.0625     0.0625    0.0625    0.0625
 0.0625   0.0625
```

Fig. 5.2.1 Cont.

and prints the heading card and the array values and then identifies the selected modes by displaying the contents of the mode identification card with an asterisk to indicate the selected mode. For example, if MODV(7) was 1, the printer would display

* FIGURE SENSOR TEST   FIGURE CONTROL SYSTEM TEST

while MODV(7) = 2 would produce

FIGURE SENSOR TEST   *FIGURE CONTROL SYSTEM TEST

MODV(1) permits the user to select between manual operation or completely automatic simulation run control. Manual control is accomplished by operating a sense switch on the computer console which is interrogated by the software. Manual control permits the operator to start and terminate the simulation run manually, a necessary feature if on line plotting of results using a strip chart or xy plotter is desired.

MODV(2) permits the user to select between online data display and offline plotting mode. In the online mode plot data is transferred directly to the display device. The offline plotting capability permits the user to store data on magnetic tape for later display. The current EAM package does not include an online plotting capability; however, online plotting is easily added with few minor modifications.

MODV(3) permits the user to eliminate all nonlinearities which may have been incorporated in hardware component models and the figure control algorithm. This capability is extremely useful for verifying the results of a linear analysis.

MODV(4) permits the operator to select either the initial alignment mode for coarse orientation of the mirror segments in tilt or axial position (Sections 3.9 and 3.10) or the final figure control mode (Sections 3.2 and 3.3).

MODV(5) determines whether the tilt or axial alignment control systems are operated if the INITIAL ALIGNMENT mode is selected.

MODV(6) is utilized to select the actuator control algorithm appropriate for force or position figure actuation.

MODV(7) provides two control system modes of operation. If the FIGURE SENSOR TEST mode is requested, EAMCS calls MAINA(6) to process the figure sensor data each time a set of NMEASQ figure measurements have been generated at a measurement position. Thus the figure error vector will be generated in a sequential fashion. This is a particularly useful display mode for the development of figure sensor data processing algorithms. If FIGURE CONTROL SYSTEM TEST is selected the sum of the squares of the NMEASQ figure measurements at each position are stored until all the measurement locations have been scanned. At this point MAINB is called to process the entire set of figure measurements. The latter approach results in a desirable reduction in the number of Sigma 2 to Sigma 5 interrogations.

MODV(8) enables the user to operate the experimental mirror control system with the actual hardware components or with software models of the figure sensor, actuators and mirror. If MODV(12) = 2, for example, the control system will use the real time control software in the Sigma 2 and the component models which always reside in the Sigma 5.

MODV(9) permits the user to operate the software in the simulation or in the actual experiment operating mode. MODV(9) permits most of the complicated operating sequence control logic which is essential for experiment operation to be skipped.

Computer memory may be saved by utilizing the reduced mirror model matrix A_r rather than the full matrix A.* The reduced matrix may be used by setting MODV(10) equal to 2.

MODV(11) provides the capability for testing the remote terminal control capability provided by the subroutine TYPCON when the EAM software is operated in the simulation mode. If MODV(11) is set to 2, the operator must provide the control commands to initialize, start and stop the figure control system. The communications may be simulated by card input-printer output or by the Sigma 5 typewriter console with appropriate device assignment through NTYPO and NTYPI.

The computer configuration may be changed using MODV(12). If MODV(12) is one all simulation computations are performed in the Sigma 5. A value of MODV(12) = 2 permits the simulation of the Sigma 5-2 operating configuration with all inter computer routine transfers performed via SUPE2 and SUPE5. This permits a complete check of the supervisory software in the Sigma 5.

5.2.3 Simulation Control Data

Basic control data for the simulation consists of the time step size, DT, the interval between output print data, TPRNT, the duration of each simulation run TEND, and the time interval, DTNOIS, between the generation of new stochastic structural disturbances. The sense switch assignment, NSSRUN, for manual control of the simulation is also input at this time.

* It is only necessary to use the complete matrix if the effects of a time-varying distributed disturbance, not adequately modelled by a set of loads or displacements applied at the actuator locations, is under investigation.

DT	TPRNT	TEND	DTNOIS
(E10.0)	(E10.0)	(E10.0)	(E10.0)
NSSRUN			
(I10)			

The value of DT should equal the real time control system cycle time Δt. TPRNT, TEND and DTNOIS should be integer multiples of Δt.

5.2.4 Run Set Identification and the Number of Runs

NRUN	NRUNM	
(I10)	(I10)	
NCXV	NCPV	NICPV
(I10)	(I10)	(I10)
(7(6X, A4))		
(7I10)		
(7(6X, A4))		
(7I10)		
(7(6X, A4))		
(7I10)		
CXM		
(7E10.0)		
CPM		
(7E10.0)		
CIPM		
(7E10.0)		

The EAM program structure permits a series of different runs to be performed without the necessity of reloading input data. This capability is provided by incorporating data editing routines EDITA, IEDITA, and arrays which store the edited data values for each run. A series of runs are assigned a run identification number NRUN which identifies the first run in the set. Subsequent runs are identified by NRUN+1, NRUN+2, etc. The number of runs is identified by the variable NRUNM.

Provisions are also included to operate the experiment with any preselected set of data. The remote terminal can be used, via TYPCON, to select the desired set of data. The required data modifications are then performed in SIMSYS.

The edited data must be associated with the elements of three arrays XV, PARV and IPARV by the addition of appropriate code in SIMSYS. The original values of XV, PARV and IPARV are stored. XV, PARV and IPARV, are reset to the original values before editing. The editing routine extracts the new element values from memory and produces the modified arrays.

The elements of XV, PARV, and IPARV which are to be modified are identified by the integer arrays JCXV, JCPV and JICPV of dimension NCXV, NCPV and NICPV, respectively. These arrays are inputed together with identifying names which are stored in the arrays NMCXV, NMCPV, and NMICPV.

The values to be used in each of the NRUNM runs are stored in the arrays CXM, CPM and ICPM.

5.2.5 Device Assignment for Manual Simulation Control

```
NTYPE
 (I10)
```

Sense switch operation cues are generated for the simulation user in the manual control mode (MODV(1)=1). The cues are displayed on the device identified by the assignment associated with the value of NTYPE. The normal display device is the console typewriter.

5.2.6 Plotting Data

NPLOTV
(I10)
DTPLOT
(E10.0)
IPLOTV
(7I10)
IMODV
(7I10)
SCALV
(7E10.0)

Data to be plotted must be transferred to the XV. In general, a larger number of variables are transferred to XV than are actually plotted. The number of XV elements to be plotted is defined by NPLOTV. The information to be plotted is stored every DTPLOT seconds. The elements of XV to be plotted are identified by the IPLOTV.

An automatic scaling provision has been added to the software. The IPLOTV(K) element of XV may be automatically scaled for plotting by setting IMODV(K) = 2. If IMODV(K) = 1, the IPLOTV(K)th element of XV is plotted using the scale defined by SCALV(K).

5.2.7 Peripheral Device Assignment

NSNSWT	NTYPI	NTYPO	NPUNCH	NMAG
(I10)	(I10)	(I10)	(I10)	(I10)

The EAM software is designed to permit a variety of computer peripheral device configurations. For example, the remote peripheral utilized to control the experiment may be assigned to card reader input-line printer output for test purposes. Similar assignments may be made for the punch and a magnetic storage device by reading appropriate values of NPUNCH and NMAG.

NSNSWT defines the interrupt assignment which is used to transfer control to the typewriter during experiment operation. Control transfer to the typewriter must be accompanied by an orderly termination of actuator motion.

5.2.8 Mirror Model Data

N	NR
(I10)	(I10)
AM	
(7E10.0)	
ASCALE	AIMSCL
(E10.0)	(E10.0)

The dimension N of the mirror model matrix AM and the number of actuators NR are read in at this point. If MODV(10) = 1, the complete NxN AM is inputed. The reduced NxNR AM is read in if MODV(10) = 2.

If the mirror matrix is not in the desired units (wavelengths/kilogram), it may be scaled by assigning a non unity value to ASCALE. If ASCALE $\neq$ 1 the computer multiplies AM by ASCALE and prints the resulting scaled matrix.

Computation of the gain matrices K_ℓ or K_o involves matrix inversion of A_{rr} or $A_r{}'A_r$. If numerical problems arise as a result of the limited dynamic range of the computer a scale factor β_{ms}(AIMSCL) may be introduced to improve numerical accuracy. The matrix inversions are then performed on the matrices.

$$D = \beta_{ms} A_{rr} \tag{5.2.1}$$

or

$$D = \beta_{ms} A_r{'} A_r \tag{5.2.2}$$

The inverse matrix is reconstructed from D^{-1} by

$$A_{rr}^{-1} = \beta_{ms} D^{-1} \tag{5.2.3}$$

or

$$\left[A_r{'} A_r\right]^{-1} = \beta_{ms} D^{-1} \tag{5.2.4}$$

5.2.9 Figure Sensor Data

FSCALE
(E10.0)
XFSV
(7E10.0)
YFSV
(7E10.0)
PSCALE
(E10.0)

The output of the figure sensor phase detector is converted to wavelengths of figure error by the scale factor FSCALE.

The x and y coordinates of the N figure measurement positions* are read in as elements of the arrays XFSV and YFSV, respectively.

* corresponding to joint locations in the finite element model.

The scale factor PSCALE converts the coordinate data to a set of values suitable for input to the figure sensor image dissector.

5.2.10 Actuator Position Data

LACTV
(7I10)

The actuators are assigned to joint positions by setting NR elements of the LACTV array to one. The other elements should be set to zero.

5.2.11 Actuator Scale Factors

ASCALV
(7E10.0)

The actuator commands m_c are converted to values suitable for processing by the Sigma 2 and the actuator hardware components by multiplying each element of m_c by the corresponding element of ASCALV. ASCALV may also be utilized to correct differences in the actuator scale factors.

5.2.12 Figure Control Algorithm

MODOP
(I10)

The figure control algorithm type may be selected by assigning an appropriate value to MODOP. If MODOP = 1, the gain matrix GAINM for the simplified linear control system is calculated by MFCS. MODOP = 2 results in computation of the linear optimal gain matrix. A value of MODOP = 3 inputs a NR by N gain matrix.

GAINM
(7E10.0)

5.2.13 Actuator Test Data

NMEASA
(I10)
DACT
(E10.0)

Test data for routine ACTCAL consists of the number of measurements to be performed and averaged NMEASA and the magnitude of the actuator command perturbation DACT.

5.2.14 Mirror Calibration Test Data

NMEASF
(I10)
DACT
(E10.0)

MIRCAL reads the number of calibration tests NMEASF to be performed and averaged and the size of the mirror test actuator command perturbation DACT.

5.2.15 Real Time Control System Parameters

NTIMSO	NWAIT	NPOS	NMINT	NMEAS	NTYO
(I10)	(I10)	(I10)	(I10)	(I10)	(I10)
DT	DTE	GAINV(1)	QGA	QGB	UFMAX
(E10.0)	(E10.0)	(E10.0)	(E10.0)	(E10.0)	(E10.0)

The real time control schedule parameters define the number of control cycles for actuator manipulation, NWAIT, the number of cycles allowed for the figure sensor output to settle after a dissector position change, NPOS, the number of control cycles between measurements, NMINT, and the number of measurements at each location, NMEAS.

The control system status is displayed on the typewriter after every NTYO complete sets of mirror figure error measurements. Currently typed data includes the elapsed operating time and the rms value of the figure measurements, PINDEX.

DT is the control system cycle time and DTE is a term which is added to T in the cycle time control loop (EAMCS) to compensate for roundoff error.

The scalar gain matrix multiplier β_g is read in as the first element of GAINV. QGA and QGB are the actuator control system gains. UFMAX is a limit imposed on the actuator command signals to prevent possible damage to the actuators or the mirror structure.

5.2.16 Figure Sensor Filter Parameters

SIGLIM	SLPMN
(E10.0)	(E10.0)
MSEQV	
(7I10)	

The digital figure error data processor required the limit on the rms measurement error SIGLIM, the extrapolation factor SLPMN for ambiguous measurements and the scanning sequence MSEQV for the N measurement points. The figure sensor looks at the point defined by MSEQV(N) first; i.e., XFSV(MSEQV(N)), YFSV(MSEQV(N)). Subsequent measurements are made at MSEQV(N-1), MSEQV(N-2), etc.

5.2.17 Figure Sensor Model Data

FSNSIG	FSTFLT
(E10.0)	(E10.0)
IRAND	
(I10)	

The figure sensor model data consists of the rms measurement noise FSNSIG, phase detector filter time constant FSTFLT, and the initial starting value IRAND for the random number generator which should be an odd integer.

5.2.18 Actuator Model Data

TACTV
(7E10.0)

The time constants for the first order actuator models are read in as NR elements of TACTV.

5.2.19 Mirror Model Data

AMM
(7E10.0)
XFDV
(7E10.0)

Data for the mirror model consists of the mirror model matrix AMM and the initial figure error XFDV. The mirror model matrix is read in in the same form as AM and scaled, if necessary, using ASCALE.

5.2.20 Initial Alignment Control System Data

LREFAV		
(7I10)		
SMXV		
(7E10.0)		
SMYV		
(7E10.0)		
BSMP	BSDP	DELU
(E10.0)	(E10.0)	(E10.0)
NHM	NIM	
(I10)	(I10)	
NTILT	NCTILT	
(I10)	(I10)	
GTILT		
(E10.0)		

The initial alignment control system data is read in by MAINC. The vector LREFAV of dimension 9 identifies the actuator allocation during initial alignment. The first three elements of LREFAV identify the elements of UFV associated with segment one. The first element provides the reference actuator for initial tilt alignment. The second and third elements identify the actuators used in the secondary tilt adjustments. The next three, and last three elements of LREFAV identify the actuators associated with the second and third segments in a similar fashion. The X and Y coordinates of the actuators are read in as the arrays SMXV and SMYV, respectively.

The peak ambiguity sensor model output BSMP and the second order coefficient BSDP are read in next. Note that BSDP must be less than zero.

The slew control system algorithm requires the actuator output perturbation DELU, the maximum number of successful control algorithm iterations NIM and the maximum number of step-size halvings NHM as input variables.

Tilt control requires the number of control computations at each computed measurement position NCTILT and the number of scan path divisions NTILT (between the reference and secondary actuator positions). The control loop gain GTILT is also required.

5.2.21 Performance Index Data

WGTV
(7E10.0)

The weighting factors for the performance index are read in as N elements of the WGTV array.

CHAPTER 6

REMOTE CONTROL OF THE EXPERIMENT

6.1 Introduction

Since the Sigma 5 - 2 computers are some distance from the experimental hardware, it is desirable to incorporate a capability for controlling the experiment from a point remote from the computation facility.

The experimental active mirror software has been designed to permit operation of the experiment from a remote location by means of a peripheral device such as a teletype, for example. Instructions required to initiate, start and stop the experiment, display and modify control system parameters and more complicated functions such as actuator test and calibration are incorporated.

Coding has also been generated to permit the automatic periodic display of important control system parameters, for monitoring purposes, on the remote terminal.

6.2 Experiment Control Commands

The remote terminal is designated by the device assignments NTYPI for input and NTYPO for output (NTYPIQ and NTYPOQ in the Sigma 2 software). The split assignment enables the card reader to be used to simulate remote input while the line printer is used for remote output during initial checkout, for example.

Conversation with the remote terminal is initiated by calling TYPCON with NENTRY = 2. TYPCON (2) is called automatically by EAMCS to request control system initialization and start instructions. During experiment operation TYPCON (2) may be called by enabling a Sigma 2 interrupt or sense switch which sets MODEQ = 3 stopping the experiment and generating a request for instructions.

TYPCON (2) requests a value for MODEQ by typing MODE = ? and waiting for the operator to respond by typing an integer in I3 format. The integer value must be greater than zero and less than 13. The functions associated with each mode value are:

MODEQ = 1 Initializes the mirror figure control system.

MODEQ = 2 Starts the mirror figure control system. EAMCS checks to see if MODEQ = 2 was preceded by MODEQ = 1 to assure that the control system is ready to start.

MODEQ = 3 Stops the mirror figure control system, freezes the figure actuators and returns control to TYPCON (2) for further instructions.

MODEQ = 4 Provides a calling sequence to test the actuators for correct operation via MFCS and ACTCAL.

MODEQ = 5 Provides a calling sequence to calibrate the mirror structure via calls to MFCS and MIRCAL.

MODEQ = 6 Initiates the diagnostic mode of operation of TYPCON. TYPCON will then request a variable name and index (indices) from the experiment operator. The operator responds by typing a variable name in (1X, A4) format. The name is checked and associated with a numerical identifier by MAINC. If the name is not a member of a stored list, an error is registered and a new name requested. The value of the numerical identifier determines whether or not an index or indices are requested of the operator. The member of the data, thus identified, is displayed on the remote terminal. The system remains in the diagnostic mode until the name DEND is submitted, resulting in a request for a new value of MODEQ.

MODEQ = 7 Provides the steps required to modify the input data to correspond to run NRUN using the stored information and editing capability of SIMSYS and a value for NRUN provided on request by the operator.

MODEQ = 8 Resumes operation of the experiment if termination has occurred during operation as a result of MODEQ = 3.

MODEQ = 9 Evaluates and types the rms figure error using PINDX.

MODEQ = 10 Initiates a parameter modification mode. The variable identification sequence for MODEQ = 6 is followed by a request for a new variable value which is accepted in (I4) or (F12.6) format. The terminal responds by retyping the new variable value.

MODEQ = 11 Unused mode.

If MODEQ is greater than 11, the terminal types MODE TOO BIG and requests a new value for MODEQ.

6.3 Experiment Monitoring Capability

The software is designed to output data useful for monitoring the active mirror experiment. The data currently consists of the rms value of the N elements of the figure error vector XFV calculated by PINDX and the total operating time of the current experiment. The operating time is the product of the number of control cycles ITIMS and the control cycle time DT.

CHAPTER 7

SUMMARY

7.1 General Features of the Digital Control System

This report describes the current version of a versatile multi-computer software system developed at MIT/DL to simulate a mirror figure control system and by simple modification to provide the control software for an experimental active mirror at the Marshall Space Flight Center.

The internally generated control laws provide for initial alignment of the segmented mirror, and simplified linear and linear optimal algorithms for fine alignment of the segmented and deformable mirror figures. The control algorithm is also designed to accept a general gain matrix for the fine figure alignment algorithm.

The software includes a digital filter to process figure sensor data. The filter operates to remove measurement ambiguities and signal noise which arise as a result of the inherent characteristics of the interferometric figure sensor.

The software is written in FORTRAN, permitting execution of the simulation on a broad spectrum of different computers.

The control software for the experiment is an integral part of the simulation. Thus, it is possible to completely check out and evaluate a programmed control algorithm by simulation before execution with the hardware is attempted.

The software is arranged so that the simulation may be operated entirely within the boundaries of one computer. In this mode it is possible to simulate operation in the two computer configuration. The simulation may also be operated in a two computer mode with the Sigma 5 simulation system utilizing the real time control in the Sigma 2.

Operation of the software with the hardware components is achieved by a simple modification of an array of input operating mode variables. Thus, it is not necessary to juggle program modules to convert from a simulation to an experiment operation mode and vice versa.

Simplified software models are provided for all components of the segmented and deformable mirror control systems. Models are included for the

1. mirror structure
2. mirror figure sensor
3. segment axial alignment (ambiguity) sensors
4. position figure actuators
5. force figure actuators

The software has been partitioned to permit the simple substitution of more elaborate models of each of the component models if desired.

An extensive remote control, diagnosis and parameter modification capability has been incorporated in the software to permit operation of the experiment from a terminal distant from the computer facility.

Data modification may be accomplished by rereading a modified input data deck, or by utilizing an automatic data editing capability and prestored values, or by directly modifying system parameters from the remote terminal.

The sequence of operator commands to the experiment is monitored to prevent errors. Thus the start command must be preceded by the initialization command, for example.

Actuator command signals to the figure actuators are limited in magnitude to prevent damage to the experiment in the event of an operator error.

The figure actuators are automatically "frozen" during figure error measurement, figure error processing and control generation and in the event of an operator or program induced termination of experiment operation. Freezing the actuator positions minimizes the effects of actuator motion on figure measurement and prevents actuator divergence during periods when the Sigma 2 computer is not available for real time component control.

Evaluation of the experimental or simulation results is facilitated by the inclusion of software to compute a number of performance indices.

Provisions have also been made for incorporation of online or offline plotting of experimental data. The plotting routine includes data acquisition, storage, and preparation for plotting. Automatic scale generation features are also included.

The software is designed to periodically display experiment status information on the operator's console for monitoring purposes. The status data currently includes the rms figure error and the experiment operating time.

APPENDIX A

EXPERIMENTAL ACTIVE MIRROR SOFTWARE LISTINGS

A.1 Introduction

This appendix contains software listings of each EAM software module with the exception of minor subroutines which appear in the library packages in Appendix B. The subroutines are presented in alphabetical order. The following general procedures were adhered to during software construction.

1. The names of one dimensional arrays end in V in general.
2. The names of two dimensional arrays end in M in general.
3. Data is generally read in and initial computations performed when a subroutine is called with NENTRY = 1.
4. Initiallizations are performed when NENTRY = 2
5. Values of NENTRY > 2 generally signify that a system computation or data transfer is being performed.

All arrays appear in one dimensional form in the software package. This convention, which follows the practice of IBM in the development of their subroutines for one and two dimensional array manipulation, has a number of important advantages including savings in memory space by the elimination of compiler generated code and the elimination of many of the problems which arise when variables are transferred via subroutine parameter lists.

For example, the array AM which represents an n x n matrix may be simply set to zero by

```
      I = N * N
      DO 2000 J = 1, I
 2000 AM(J) = 0.0                                  (A.1.1)
```

whereas the two dimensional n x n array BM requires the following code to be zeroed

```
      DO 2000 I = 1, N
      DO 2000 J = 1, N
 2000 BM(I, J) = 0.0                               (A.1.2)
```

Note that the computer, which treats all arrays as one dimensional, must compute each storage location L of the I, Jth element in (A.1.2) by a computation similar to

$$L = (J - 1) * N + I + (L_r - 1) \tag{A.1.3}$$

where L_r is the necessary address of the array BM. In the case of (A.1.1) L is merely

$$L = I + (L_r - 1) \tag{A.1.4}$$

Suppose that the arrays AM and BM are to be passed to a subroutine as parameters. The array AM may be dimensioned

```
      DIMENSION AM(1)                              (A.1.5)
```

in the subroutine regardless of the value of N in the calling program whereas BM must be dimensioned

```
      DIMENSION BM(N, N)                           (A.1.6)
```

in both the main program and the subroutine. This leads to the possibility of errors and restricts the usefulness of the subroutine.

The data block utilized to transfer information to or from the Sigma 2 is labelled SIGTWO. Variables utilized by both the Sigma 2 and Sigma 5 software are identified in the data block by the suffix Q in the case of integer data or the prefix Q in the case of floating point variables. The SIGTWO block arrays QUFAV and MODVQ correspond to UFAV and MODV in the Sigma 5, for example.

```
 SUBROUTINE  ACTCAL(NENTRY)
 SUBROUTINE  ACTCMD(NENTRY)
 SUBROUTINE  ACTMDL(NENTRY,IENTRY)
 SUBROUTINE  EAMCS(NENTRY)
 SUBROUTINE  FIGSEN(NENTRY,I)
 SUBROUTINE  FSMDL(NENTRY,IENTRY)
 SUBROUTINE  MAINA(NENTRY)
 SUBROUTINE  MAINB(NENTRY)
 SUBROUTINE  MAINC(NENTRY)
 SUBROUTINE  MFCS(NENTRY)
 SUBROUTINE  MIRCAL(NENTRY)
 SUBROUTINE  MIRMDL(NENTRY,IACT)
 SUBROUTINE  PINDX(NENTRY,PINDEX,YV)
 SUBROUTINE  PLRT(NENTRY,XV,T,DT,NRUN)
 SUBROUTINE  RESPON(NENTRY)
 SUBROUTINE  SIMSYS(NENTRY)
 SUBROUTINE  STORED(NENTRY,RANG,WIDTH,SPAC,SCALV,X,Y,XSPRED,NPLOTV,
1 NPTS,NRUN)
 SUBROUTINE  SUPE2
 MAIN PROG   SUPE5
 SUBROUTINE  TYPCON(NENTRY)
```

```
      SUBROUTINE ACTCAL(NENTRY)                                         EAM10000
C                                                                       EAM10010
C     SUBROUTINE TO TEST FIGURE ACTUATORS                               EAM10020
C                                                                       EAM10030
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START                         EAM10040
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),         EAM10050
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),         EAM10060
     2 GAINM(1600),ASV(3)                                               EAM10070
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,     EAM10080
     1 DUMVA,GAINV,GAINM,ASV                                            EAM10090
C                                                                       EAM10100
      DIMENSION LACTV(20)                                               EAM10110
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM10120
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM10130
C                                                                       EAM10140
      DIMENSION AM(400),AIM(400)                                        EAM10150
      COMMON/BLKMFC/AM,AIM                                              EAM10160
C                                                                       EAM10170
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                EAM10180
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),            EAM10190
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),      EAM10200
     3 MODV(20)                                                         EAM10210
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM10220
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM10230
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM10240
C                                                                       EAM10250
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)             EAM10260
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM10270
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END                           EAM10280
C                                                                       EAM10290
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM10300
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM10310
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM10320
     2 QASV(3)                                                          EAM10330
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM10340
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM10350
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM10360
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM10370
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM10380
C                                                                       EAM10390
      DIMENSION DUMVD(20)                                               EAM10400
C                                                                       EAM10410
 1000 FORMAT(7H ACTCAL)                                                 EAM10420
 1002 FORMAT(/,3X,12HACTOUT/ACTIN)                                      EAM10430
C                                                                       EAM10440
      GO TO (1,2,3,4,5,6),NENTRY                                        EAM10450
C                                                                       EAM10460
C     INPUT DATA                                                        EAM10470
 1    PRINT 1000                                                        EAM10480
      CALL IRANDP(1,NMEASA,IA,IA,IA,IA,IA,IA,4)                         EAM10490
      CALL RANDPD(1,DACT,DA,DA,DA,DA,DA,DA,4)                           EAM10500
      DB=DACT*2.0                                                       EAM10510
      DB=1.0/(NMEASA*DB)                                                EAM10520
      RETURN                                                            EAM10530
C                                                                       EAM10540
C     INITIALIZATION                                                    EAM10550
 2    RETURN                                                            EAM10560
```

```
C
C     ACTUATOR CALIBRATION
C     RETURN TO SIGMA 2 TO INITIALIZE EAMCS
 3    IGOA=MODV(12)
      GO TO (2213,2200),IGOA
C*****EAM SOFTWARE TEST CODING******************************************
 2213 CALL EAMCS(8)
      GO TO 4
C*****EAM SOFTWARE TEST CODING******************************************
 2200 CALL MARK(1,22,8,8,4)
      RETURN
C
 4    SGAIN=GAINV(1)
      GAINV(1)=0.0
      NTIMS=NWAIT
      NTIMSO=NTIMS
      DO 2202 I=1,NR
 2202 DUMV(I)=0.0
      J=0
C     DETERMINE THE STEADY STATE ACTUATOR GAINS NMEASA TIMES AND
C     AVERAGE THE RESULTS
 2208 J=J+1
      IF(J-NMEASA)2209,2209,2210
 2209 DO 2203 K=1,NR
      UFV(K)=-DACT
 2203 QUFV(K)=UFV(K)*ASCALV(K)
C     RETURN TO SIGMA 2 TO ADJUST THE ACTUATORS
      GO TO (2212,2204),IGOA
C*****EAM SOFTWARE TEST CODING******************************************
 2212 CALL EAMCS(3)
      GO TO 5
C*****EAM SOFTWARE TEST CODING******************************************
 2204 CALL MARK(1,22,3,8,5)
      RETURN
C
 5    DO 2205 K=1,NR
      UFAV(K)=QUFAV(K)/ASCALV(K)
      DUMVD(K)=UFAV(K)
      UFV(K)=DACT
 2205 QUFV(K)=UFV(K)*ASCALV(K)
C     RETURN TO SIGMA 2 TO ADJUST THE ACTUATORS
      GO TO (2211,2206),IGOA
C*****EAM SOFTWARE TEST CODING******************************************
 2211 CALL EAMCS(3)
      GO TO 6
C*****EAM SOFTWARE TEST CODING******************************************
 2206 CALL MARK(1,22,3,8,6)
      RETURN
C
 6    DO 2201 K=1,NR
      UFAV(K)=QUFAV(K)/ASCALV(K)
 2201 DUMV(K)=(UFAV(K)-DUMVD(K))+DUMV(K)
      GO TO 2208
 2210 CONTINUE
      DO 2207 I=1,NR
      UFV(I)=0.0
      QUFV(I)=0.0
 2207 DUMV(I)=DUMV(I)*DB                                                EAM11140
C                                                                       EAM11150
C     PRINT OUT ACTUATOR SCALE VECTOR                                   EAM11160
      PRINT 1002                                                        EAM11170
      CALL MXRNP(DUMV,1,NR,3)                                           EAM11180
      GAINV(1)=SGAIN                                                    EAM11190
      RETURN                                                            EAM11200
C                                                                       EAM11210
      END                                                               EAM11220
```

```
      SUBROUTINE ACTCMD(NENTRY)                                         EAM11230
C                                                                       EAM11240
C     SUBROUTINE TO SCALE AND TRANSFER ACTUATOR COMMANDS AND ACTUATOR OUEAM11250
C     MEASUREMENTS.                                                     EAM11260
C                                                                       EAM11270
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM11280
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM11290
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM11300
     2 QASV(3)                                                          EAM11310
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM11320
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM11330
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM11340
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM11350
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM11360
C                                                                       EAM11370
      GO TO(1,2,3,4,5),NENTRY                                           EAM11380
C                                                                       EAM11390
C     INPUT DATA                                                        EAM11400
 1    RETURN                                                            EAM11410
C                                                                       EAM11420
C     INITIALIZATION                                                    EAM11430
 2    SQGA=QGA                                                          EAM11440
      RETURN                                                            EAM11450
C                                                                       EAM11460
C     TRANSFER ACTUATOR COMMANDS AND MEASURE ACTUATER OUTPUTS           EAM11470
C                                                                       EAM11480
 3    I=0                                                               EAM11490
 2309 I=I+1                                                             EAM11500
      IF(I-NRQ)2308,2308,2303                                           EAM11510
C     LIMIT QUFV(I)                                                     EAM11520
 2308 IF(QUFV(I)-QUFMAX)2304,2304,2305                                  EAM11530
 2304 IF(QUFV(I)+QUFMAX)2306,2307,2307                                  EAM11540
 2305 QUFV(I)=QUFMAX                                                    EAM11550
      GO TO 2307                                                        EAM11560
 2306 QUFV(I)=-QUFMAX                                                   EAM11570
C     RETURN TO SIGMA 5 TO MODEL ACTUATORS IF MODVQ(8)=1                EAM11580
 2307 IGO=MODVQ(8)                                                      EAM11590
      GO TO(2301,2311),IGO                                              EAM11600
 2301 NFLGA=7                                                           EAM11610
      NFLGB=I                                                           EAM11620
      IGO=MODVQ(12)                                                     EAM11630
      GO TO (2302,2310),IGO                                             EAM11640
C*****EAM SOFTWARE TEST CODING******************************************EAM11650
 2302 CALL ACTMDL(3,I)                                                  EAM11660
      GO TO 4                                                           EAM11670
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C*****EAM SOFTWARE TEST CODING*******************************************EAM11680
 2310 RETURN                                                            EAM11690
C                                                                       EAM11700
 4    GO TO 2309                                                        EAM11710
C                                                                       EAM11720
 2311 CONTINUE                                                          EAM11730
C     INSERT SOFTWARE TO MEASURE ACTUATOR POSITION                      EAM11740
C     QUFAV(I)=ACTUATOR POSITION                                        EAM11750
C     CALCULATE THE ACTUATOR ERROR                                      EAM11760
      DA=QUFV(I)-QUFAV(I)                                               EAM11770
C     ACCUMULATE THE ERROR IN QUFERV                                    EAM11780
      QUFERV(I)=QUFERV(I)+QDT*QGB*DA                                    EAM11790
C     FORM THE ACTUATOR CONTROL                                         EAM11800
      DA=QGA*(DA+QUFERV(I))                                             EAM11810
C     SET ACTUATOR CONTROL EQUAL TO 0 IF NENTRY=5                       EAM11820
      GO TO(2402,2402,2402,2402,2401),NENTRY                            EAM11830
 2401 DA=0.0                                                            EAM11840
 2402 CONTINUE                                                          EAM11850
C     INSERT SOFTWARE TO TRANSFER ACTUATOR COMMANDS TO ACTUATORS        EAM11860
C     DA IS THE INPUT FOT THE ITH ACTUATOR                              EAM11870
      GO TO 2309                                                        EAM11880
 2303 NFLGA=6                                                           EAM11890
      RETURN                                                            EAM11900
C                                                                       EAM11910
C     FREEZE ACTUATORS                                                  EAM11920
 5    QGA=0.0                                                           EAM11930
      NFLGA=6                                                           EAM11940
      RETURN                                                            EAM11950
C                                                                       EAM11960
C     RELEASE ACTUATOR OUTPUTS                                          EAM11970
C                                                                       EAM11980
 6    QGA=SQGA                                                          EAM11990
      NFLGA=6                                                           EAM12000
      RETURN                                                            EAM12010
C                                                                       EAM12020
C                                                                       EAM12030
      END                                                               EAM12040
```

```
      SUBROUTINE ACTMDL(NENTRY,IENTRY)                                  EAM12050
C                                                                       EAM12060
C     SIMPLIFIED ACTUATOR MODEL FOR TESTING THE EAM SOFTWARE PACKAGE    EAM12070
C                                                                       EAM12080
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START                         EAM12090
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),         EAM12100
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),         EAM12110
     2 GAINM(1600),ASV(3)                                               EAM12120
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,     EAM12130
     1 DUMVA,GAINV,GAINM,ASV                                            EAM12140
C                                                                       EAM12150
      DIMENSION LACTV(20)                                               EAM12160
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM12170
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM12180
```

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C                                                                       EAM12190
      DIMENSION AM(400),AIM(400)                                        EAM12200
      COMMON/BLKMFC/AM,AIM                                              EAM12210
C                                                                       EAM12220
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                EAM12230
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),            EAM12240
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),      EAM12250
     3 MODV(20)                                                         EAM12260
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM12270
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM12280
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM12290
C                                                                       EAM12300
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)             EAM12310
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM12320
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END                           EAM12330
C                                                                       EAM12340
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM12350
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM12360
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM12370
     2 QASV(3)                                                          EAM12380
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM12390
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM12400
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM12410
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM12420
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM12430
C                                                                       EAM12440
      DIMENSION TACTV(20),AGAMV(20),APHIV(20)                           EAM12450
C                                                                       EAM12460
 1000 FORMAT(7H ACTMDL)                                                 EAM12470
 1001 FORMAT(10X,5HAPHIV)                                               EAM12480
 1002 FORMAT(10X,5HAGAMV)                                               EAM12490
C                                                                       EAM12500
      I=IENTRY                                                          EAM12510
      GO TO(1,2,3),NENTRY                                               EAM12520
C                                                                       EAM12530
C     INPUT DATA                                                        EAM12540
 1    PRINT 1000                                                        EAM12550
      CALL MXRNP(TACTV,1,NR,4)                                          EAM12560
      RETURN                                                            EAM12570
C                                                                       EAM12580
C     INITIALIZATION                                                    EAM12590
C     CONSTRUCT THE ACTUATOR MODELS                                     EAM12600
 2    DO 2001 J=1,NR                                                    EAM12610
      APHIV(J)=0.0                                                      EAM12620
      AGAMV(J)=1.0                                                      EAM12630
      IF(TACTV(J))2001,2001,2002                                        EAM12640
 2002 DA=-(DT/TACTV(J))                                                 EAM12650
C     CALCULATE THE STATE TRANSITION MATRICES FOR THE ACTUATORS         EAM12660
      APHIV(J)=EXP(DA)                                                  EAM12670
C     CALCULATE THE INPUT TRANSITION MATRICES FOR THE ACTUATORS         EAM12680
      AGAMV(J)=1.0-APHIV(J)                                             EAM12690
 2001 CONTINUE                                                          EAM12700
      PRINT 1001                                                        EAM12710
      CALL MXRNP(APHIV,1,NR,3)                                          EAM12720
      PRINT 1002                                                        EAM12730
      CALL MXRNP(AGAMV,1,NR,3)                                          EAM12740
      RETURN                                                            EAM12750
C                                                                       EAM12760
```

```
C     SIMULATION
C     OBTAIN UFV FROM THE SIGMA 2
 3    UFV(I)=QUFV(I)/ASCALV(I)
C     SIMULATE THE ACTUATOR DYNAMICS IN THE SIGMA 5
      UFAV(I)=APHIV(I)*UFAV(I)+AGAMV(I)*UFV(I)
C     TRANSFER NEW VALUE OF UFV TO SIGMA 2
      QUFAV(I)=UFAV(I)*ASCALV(I)
      RETURN
C
      END
```

```
      SUBROUTINE EAMCS(NENTRY)
C
C     SUBROUTINE TO REALIZE THE REAL TIME CONTROL SYSTEM FOR THE
C     EXPERIMENTAL ACTIVE MIRROR
C
C     SIGMA 2 DIMENSION STATEMENTS START
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),
     2 QASV(3)
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ
C     SIGMA 2 DIMENSION STATEMENTS END
C
 1002 FORMAT(16H INITIALIZE MFCS)
 1005 FORMAT(11H START MFCS)
 1003 FORMAT(10H BEGIN RUN)
 1009 FORMAT(15H SEQUENCE ERROR)
 1010 FORMAT(11H MODE NOT =,I2)
C
      GO TO(1,2,3,3,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19),NENTRY
C
C     INPUT DATA
 1    RETURN
C
C     INITIALIZATION
C
 2    WRITE(NTYPOQ,1003)
      NFLGB=1
      CALL TYPCON(1)
      CALL ACTCMD(2)
C
C     INITIALIZE ACTIVE MIRROR
 9    WRITE(NTYPOQ,1002)
      MODES=1
      NFLGA=1
      IGOA=MODVQ(12)
      GO TO (2205,2206),IGOA
 2206 RETURN
```

```
C                                                                       EAM13270
 2205 CALL TYPCON(2)                                                    EAM13280
 10   IF(MODEQ-MODES)2229,2230,2229                                     EAM13290
 2229 WRITE(NTYPOQ,1010) MODES                                          EAM13300
      GO TO 2                                                           EAM13310
 2230 JSENS=1                                                           EAM13320
      IGOA=MODVQ(12)                                                    EAM13330
      ISENS=1                                                           EAM13340
      LSENS=MSEQVQ(NQ)                                                  EAM13350
      MSENS=0                                                           EAM13360
      QXF=0.0                                                           EAM13370
      SXF=0.0                                                           EAM13380
      SXFXF=0.0                                                         EAM13390
C     SET ACTUATOR INTEGRAL COMPENSATORS TO ZERO                        EAM13400
      DO 2232 I=1,NRQ                                                   EAM13410
 2232 QUFERV(I)=0.0                                                     EAM13420
C     SET STORAGE VECTORS FOR SXF AND SXFXF=0                           EAM13430
      DO 2134 I=1,NQ                                                    EAM13440
      QDUMVB(I)=0.0                                                     EAM13450
 2134 QDUMVC(I)=0.0                                                     EAM13460
      IF(NENTRY-8)2233,2231,2233                                        EAM13470
 2231 NFLGA=6                                                           EAM13480
      RETURN                                                            EAM13490
C                                                                       EAM13500
C     START ACTIVE MIRROR                                               EAM13510
 2233 MODES=2                                                           EAM13520
      WRITE(NTYPOQ,1005)                                                EAM13530
      NFLGA=2                                                           EAM13540
      GO TO(2235,2237),IGOA                                             EAM13550
 2235 CALL TYPCON(2)                                                    EAM13560
 11   IF(MODEQ-MODES)2,2236,2                                           EAM13570
 2236 NFLGA=6                                                           EAM13580
 2237 RETURN                                                            EAM13590
C                                                                       EAM13600
C     CONTROL SYSTEM COMPUTATIONS                                       EAM13610
C     ESTABLISH STARTING TIME                                           EAM13620
 3    CALL REALT(T)                                                     EAM13630
      TSTORE=T                                                          EAM13640
      ITIMS=0                                                           EAM13650
C     PERFORM CONTROL LOOP OPERATIONS FOR NTIMSQ CYCLES                 EAM13660
 2400 ITIMS=ITIMS+1                                                     EAM13670
      IF(ITIMS-NTIMSQ)2401,2401,2402                                    EAM13680
C     NORMAL TERMINATION TO SIGMA 5 FOR FURTHER INSTRUCTIONS            EAM13690
 2402 IGO=MODVQ(9)                                                      EAM13700
      GO TO(2236,2702),IGO                                              EAM13710
C                                                                       EAM13720
C     FIGURE SENSOR CONTROL STRUCTURE                                   EAM13730
C                                                                       EAM13740
C     MEASURE FIGURE ERRORS EVERY NSENSQ*DT SECONDS                     EAM13750
 2401 JSENS=JSENS-1                                                     EAM13760
      GO TO(2301,2302,2303,2304,2305),ISENS                             EAM13770
 2301 IF(JSENS)2310,2310,2390                                           EAM13780
 2310 ISENS=2                                                           EAM13790
      JSENS=NSENSQ                                                      EAM13800
      JWAIT=NWAITQ                                                      EAM13810
      MSENS=NQ                                                          EAM13820
 12   GO TO 2390                                                        EAM13830
C     WAIT NWAITQ*DT SECONDS FOR THE ACTUATOR OUTPUTS TO STABILIZE      EAM13840
 2302 JWAIT=JWAIT-1                                                     EAM13850
      IF(JWAIT)2320,2320,2390                                           EAM13860
 2320 ISENS=3                                                           EAM13870
```

```
C     FREEZE ACTUATOR POSITIONS                                         EAM13880
      CALL ACTCMD(5)                                                    EAM13890
C     RETURN TO SIGMA 5 SOFTWARE TO UPDATE MIRROR MODEL OUTPUTS         EAM13900
C     IF MODVQ(8)=1                                                     EAM13910
      IGO=MODVQ(8)                                                      EAM13920
      GO TO(2329,7),IGO                                                 EAM13930
 2329 NFLGA=4                                                           EAM13940
 2322 GO TO (2323,2324),IGOA                                            EAM13950
 2324 RETURN                                                            EAM13960
C*****EAM SOFTWARE TEST CODING******************************************EAM13970
 2323 CALL MIRMDL(3,I)                                                  EAM13980
      GO TO 7                                                           EAM13990
C*****EAM SOFTWARE TEST CODING******************************************EAM14000
C     TRANSFER POSITION COORDINATES TO IMAGE DISSECTOR                  EAM14010
    7 CONTINUE                                                          EAM14020
 2303 LSENS=MSEQVQ(MSENS)                                               EAM14030
C     POSITION FIGURE SENSOR IMAGE DISSECTOR                            EAM14040
      NFLGA=5                                                           EAM14050
      NFLGB=LSENS                                                       EAM14060
      GO TO (2325,2326),IGOA                                            EAM14070
 2326 RETURN                                                            EAM14080
C                                                                       EAM14090
 2325 CALL FIGSEN(2,LSENS)                                              EAM14100
   13 JWAIT=NPOSQ                                                       EAM14110
      ISENS=4                                                           EAM14120
      GO TO 2390                                                        EAM14130
C     WAIT NPOSQ*DT FOR THE MEASUREMENT POSITION TO STABILIZE           EAM14140
 2304 JWAIT=JWAIT-1                                                     EAM14150
      IF(JWAIT)2340,2340,2390                                           EAM14160
 2340 ISENS=5                                                           EAM14170
      JWAIT=NMINTQ                                                      EAM14180
      JMEAS=NMEASQ                                                      EAM14190
      KMEAS=0                                                           EAM14200
      SXF=0.0                                                           EAM14210
      SXFXF=0.0                                                         EAM14220
      GO TO 2390                                                        EAM14230
C     TAKE NMEASQ MEASUREMENTS AT INTERVALS OF NMINTQ*DT SECONDS AT EACHEAM14240
C     MEASUREMENT POINT                                                 EAM14250
 2305 JWAIT=JWAIT-1                                                     EAM14260
      IF(JWAIT)2350,2350,2390                                           EAM14270
C     TAKE FIGURE ERROR PHASE MEASUREMENT                               EAM14280
 2350 NFLGA=16                                                          EAM14290
      NFLGB=LSENS                                                       EAM14300
      GO TO(2327,2328),IGOA                                             EAM14310
 2328 RETURN                                                            EAM14320
C                                                                       EAM14330
 2327 CALL FIGSEN(3,LSENS)                                              EAM14340
   14 JMEAS=JMEAS-1                                                     EAM14350
      KMEAS=KMEAS+1                                                     EAM14360
      SXF=SXF+QXF                                                       EAM14370
      SXFXF=SXFXF+QXF*QXF                                               EAM14380
      JWAIT=NMINTQ                                                      EAM14390
C     CHECK TO SEE IF NMEASQ MEASUREMENTS HAVE BEEN MADE                EAM14400
      IF(JMEAS)2351,2351,2390                                           EAM14410
C                                                                       EAM14420
C     STORE THE SUM OF THE FIGURE MEASUREMENTS IN QDUMVB                EAM14430
 2351 QDUMVB(LSENS)=SXF                                                 EAM14440
C     STORE THE SUM OF THE SQUARES OF THE FIGURE MEASUREMENTS IN QDUMVC EAM14450
      QDUMVC(LSENS)=SXFXF                                               EAM14460
C     RETURN TO SIGMA 5 TO FILTER FIGURE ERROR DATA                     EAM14470
C     IF MODVQ(7)=1 CALCULATE THE FIGURE ERROR AFTER EVERY NMEASQ       EAM14480
```

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C     MEASUREMENTS                                                      EAM14490
      IGO=MODVQ(7)                                                      EAM14500
      GO TO(2356,5),IGO                                                 EAM14510
 2356 CONTINUE                                                          EAM14520
      NFLGA=8                                                           EAM14530
      GO TO(2357,2354),IGOA                                             EAM14540
 2354 RETURN                                                            EAM14550
C                                                                       EAM14560
C*****EAM SOFTWARE TEST CODING******************************************EAM14570
 2357 CALL MAINA(6)                                                     EAM14580
      GO TO 5                                                           EAM14590
C*****EAM SOFTWARE TEST CODING******************************************EAM14600
C     ENTRY POINT TO EAMCS AT COMPLETION OF FIGURE ERROR COMPUTATIONS   EAM14610
 5    CONTINUE                                                          EAM14620
      MSENS=MSENS-1                                                     EAM14630
      ISENS=3                                                           EAM14640
C     TERMINATE THE MEASUREMENT MODE IF THE FIGURE ERROR HAS BEEN       EAM14650
C     OBTAINED FOR ALL NQ POSITIONS                                     EAM14660
      IF(MSENS)2352,2352,2303                                           EAM14670
 2352 ISENS=1                                                           EAM14680
C                                                                       EAM14690
C     RETURN TO SIGMA 5 TO CALCULATE NEW FIGURE CONTROL                 EAM14700
 15   NFLGA=17                                                          EAM14710
      NFLGC=1                                                           EAM14720
      GO TO (2358,2359),IGOA                                            EAM14730
 2359 RETURN                                                            EAM14740
C                                                                       EAM14750
 18   NFLGA=18                                                          EAM14760
      RETURN                                                            EAM14770
C                                                                       EAM14780
C*****EAM SOFTWARE TEST CODING******************************************EAM14790
 2358 CALL MAINA(7)                                                     EAM14800
      CALL MAINA(5)                                                     EAM14810
C*****EAM SOFTWARE TEST CODING******************************************EAM14820
C                                                                       EAM14830
C     ENTRY POINT TO EAMCS AT COMPLETION OF CONTROL COMPUTATION         EAM14840
 6    CONTINUE                                                          EAM14850
C                                                                       EAM14860
C     PRINT OUTPUT DATA ON THE REMOTE IO DEVICE EVERY NTYO TIMES THE    EAM14870
C     CONTROL IS CALCULATED                                             EAM14880
      GO TO(2361,2362),NFLGC                                            EAM14890
 2362 QDUMVA(2)=ITIMS*QDT                                               EAM14900
C     CALCULATE CONTROL SYSTEM OPERATING.TIME                           EAM14910
      CALL TYPCON(9)                                                    EAM14920
 2361 CONTINUE                                                          EAM14930
C                                                                       EAM14940
C     RELEASE ACTUATORS                                                 EAM14950
      CALL ACTCMD(6)                                                    EAM14960
C                                                                       EAM14970
C     SET POSITION ACTUATOR COUNTER TO NCVELQ                           EAM14980
      ICVEL=NCVELQ                                                      EAM14990
C     FREEZE ACTUATORS AFTER NCVELQ CONTROL CYCLES                      EAM15000
 2390 IGO=MODVQ(6)                                                      EAM15010
      GO TO(2396,2397),IGO                                              EAM15020
 2397 ICVEL=ICVEL-1                                                     EAM15030
      IF(ICVEL)2399,2399,2396                                           EAM15040
C     FREEZE ACTUATORS                                                  EAM15050
 2399 CALL ACTCMD(5)                                                    EAM15060
C                                                                       EAM15070
C     TRANSFER COMMANDS TO ACTUATOR CONTROL SYSTEM                      EAM15080
 2396 NFLGA=9                                                           EAM15090
      GO TO (2393,2394),IGOA                                            EAM15100
 2394 RETURN
C
 2393 CALL ACTCMD(3)
 16   CONTINUE
C
C     STORE IMPORTANT PARAMETERS IN DUMVA FOR DIAGNOSTIC PURPOSES
C     EVERY CYCLE
      QDUMVA(7)=LSENS
      QDUMVA(8)=JMEAS
      QDUMVA(9)=JWAIT
      QDUMVA(10)=JSENS
      QDUMVA(11)=ISENS
C
C     TRANSFER EAM SYSTEM VARIABLES TO SIMULATION SYSTEM ROUTINES FOR
C     FOR DISPLAY AND FURTHER PROCESSING IF MODVQ(8)=1
      IGO=MODVQ(8)
      GO TO(2391,2392),IGO
 2391 NFLGA=10
      NFLGB=LSENS
      GO TO(2392,2395),IGOA
 2395 RETURN
C*****EAM SOFTWARE TEST CODING*****************************************
 2392 CALL FSMDL(5,LSENS)
C*****EAM SOFTWARE TEST CODING*****************************************
C
 17   IGO=MODVQ(9)
      GO TO(2400,2700),IGO
C
C     INTERRUPT FIGURE CONTROL, FREEZE ACTUATORS AND TRANSFER TO
C     TO TYPCON FOR INSTRUCTIONS IF MODEQ=3
 2700 GO TO(2703,2703,2702),MODEQ
C     STORE CURRENT TIME
 2702 CALL REALT(STA)
C     FREEZE ACTUATOR OUTPUTS
      CALL ACTCMD(5)
      CALL ACTCMD(3)
C     TRANSFER TO TYPCON FOR FURTHER INSTRUCTIONS
      NFLGA=21
      CALL TYPCON(2)
C     RESET TIME
 19   CALL REALT(T)
      TSTORE=T-STA+TSTORE
C
C     CYCLE TIME CONTROL
 2703 CALL REALT(T)
      IF(T+QDTE-TSTORE)2703,2701,2701
 2701 TSTORE=TSTORE+QDT
      GO TO 2400
C
C     INITIALIZE  EAMCS WITHOUT INTERROGATING TYPCON
 8    GO TO 2230
C
      END
      SUBROUTINE FIGSEN(NENTRY,I)                                       EAM15640
C                                                                       EAM15650
C     SUBROUTINE TO MEASURE THE FIGURE ERROR XFV(I) AT A DISCRETE POINT EAM15660
C     COORDINATES XFSV(I),YFSV(I) ON THE REFLECTING SURFACE OF THE MIRROEAM15670
C                                                                       EAM15680
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM15690
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM15700
     1QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),    EAM15710
     2QASV(3)                                                           EAM15720
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM15730
     1MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,     EAM15740
     2NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,         EAM15750
     3QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ           EAM15760
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM15770
C                                                                       EAM15780
      GO TO(1,2,3,4),NENTRY                                             EAM15790
C                                                                       EAM15800
C     INPUT DATA AND INITIALIZATION                                     EAM15810
 1    RETURN                                                            EAM15820
C                                                                       EAM15830
C     TRANSFER THE MEASUREMENT POSITION COORDINATES TO THE IMAGE        EAM15840
C     DISSECTOR                                                         EAM15850
C     SKIP POSITION COORDINATE TRANSFER IF MODV(8)=1                    EAM15860
 2    IGO=MODVQ(8)                                                      EAM15870
      GO TO(2201,2202),IGO                                              EAM15880
 2202 X=QXFSV(I)                                                        EAM15890
      Y=QYFSV(I)                                                        EAM15900
C     X AND Y ARE THE COORDINATES OF THE MEASUREMENT POSITION           EAM15910
C     INSERT DTOA SOFTWARE HERE TO POSITION IMAGE DISSECTOR             EAM15920
 2201 NFLGA=6                                                           EAM15930
      RETURN                                                            EAM15940
C                                                                       EAM15950
C     SAMPLE THE FIGURE SENSOR PHASE DETECTOR FILTER OUTPUT             EAM15960
C     RETURN TO SIGMA 5 TO MODEL FIGURE SENSOR IF MODVQ(8)=1            EAM15970
 3    IGO=MODVQ(8)                                                      EAM15980
      GO TO(2301,2302),IGO                                              EAM15990
 2301 NFLGA=11                                                          EAM16000
      NFLGB=I                                                           EAM16010
      IGO=MODVQ(12)                                                     EAM16020
      GO TO (2304,2303),IGO                                             EAM16030
 2303 RETURN                                                            EAM16040
C*****EAM SOFTWARE TEST CODING******************************************EAM16050
 2304 CALL FSMDL(3,I)                                                   EAM16060
      GO TO 4                                                           EAM16070
C*****EAM SOFTWARE TEST CODING******************************************EAM16080
C                                                                       EAM16090
 2302 CONTINUE                                                          EAM16100
C     QXF IS THE FIGURE SENSOR PHASE DETECTOR FILTER OUTPUT             EAM16110
C     INSERT ATOD SOFTWARE HERE TO INTERROGATE FIGURE SENSOR            EAM16120
 4    CONTINUE                                                          EAM16130
      NFLGA=6                                                           EAM16140
      RETURN                                                            EAM16150
C                                                                       EAM16160
      END                                                               EAM16170
      SUBROUTINE FSMDL(NENTRY,IENTRY)                                   EAM16180
C                                                                       EAM16190
C     SIMPLIFIED FIGURE SENSOR MODEL TO TEST THE EAM SOFTWARE PACKAGE   EAM16200
C     MODEL SIMULATES THE FIGURE SENSOR FOR INPUT ERRORS IN THE RANGE   EAM16210
C     FROM -3/4 TO +3/4 WAVELENGTHS                                     EAM16220
C                                                                       EAM16230
C     SIGMA 5 TYPE A DIMENSION STATEMENTS START                         EAM16240
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),         EAM16250
     1 YFSV(20),XFRV(20),DOMV(20),UFAV(20),DUMVA(20),GAINV(10),         EAM16260
     2 GAINM(1600),ASV(3)                                               EAM16270
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DOMV,UFAV,     EAM16280
     1 DUMVA,GAINV,GAINM,ASV                                            EAM16290
C                                                                       EAM16300
      DIMENSION LACTV(20)                                               EAM16310
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM16320
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM16330
C                                                                       EAM16340
      DIMENSION AM(400),AIM(400)                                        EAM16350
      COMMON/BLKMFC/AM,AIM                                              EAM16360
C                                                                       EAM16370
      COMMON/BLKT/T,DT,DTH,DTPLOT,DTNOIS,TPHI,TPRNT,TEND                EAM16380
C                                                                       EAM16390
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                EAM16400
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),            EAM16410
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),      EAM16420
     3 MODV(20)                                                         EAM16430
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM16440
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM16450
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM16460
C                                                                       EAM16470
      DIMENSION XV(50),NAMV(50),DUMV(20),DUMM(400),PARV(50),IPARV(50),  EAM16480
     1 SXV(50),SPARV(50),ISPARV(50),IDUMV(20)                           EAM16490
      COMMON/BLKSIM/XV,NAMV,DUMV,DUMM,PARV,IPARV,SXV,SPARV,ISPARV,      EAM16500
     1 IDUMV                                                            EAM16510
C                                                                       EAM16520
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)             EAM16530
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM16540
C     SIGMA 5 TYPE A DIMENSION STATEMENTS END                           EAM16550
C                                                                       EAM16560
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM16570
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM16580
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM16590
     2 QASV(3)                                                          EAM16600
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM16610
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM16620
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM16630
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM16640
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM16650
C                                                                       EAM16660
 1000 FORMAT(6H FSMDL)                                                  EAM16670
 1001 FORMAT(10X,5HFSPHI,10X,5HFSGAM,/,2F15.6)                          EAM16680
C                                                                       EAM16690
      I=IENTRY                                                          EAM16700
      GO TO(1,2,3,4,5,6),NENTRY                                         EAM16710
C                                                                       EAM16720
C     INPUT DATA                                                        EAM16730
 1    PRINT 1000                                                        EAM16740
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C     READ IN DATA FOR FIGURE SENSOR NOISE MODEL                        EAM16750
      CALL RANDPD( 2,FSNSIG,FSTFLT,DA,DA,DA,DA,DA,4)                    EAM16760
      CALL IRANDP( 1,IRAND,IA,IA,IA,IA,IA,IA,4)                         EAM16770
      IB=N+3                                                            EAM16780
      IRANDS=IRAND                                                      EAM16790
      GAINV( 4)=FSTFLT                                                  EAM16800
      GAINV( 6)=FSNSIG                                                  EAM16810
      RETURN                                                            EAM16820
C                                                                       EAM16830
C     INITIALIZATION                                                    EAM16840
 2    CONTINUE                                                          EAM16850
      IRAND=IRANDS                                                      EAM16860
      FSNSIG=GAINV( 6)                                                  EAM16870
      FSTFLT=GAINV( 4)                                                  EAM16880
      FSFLTO=0.0                                                        EAM16890
      FSNOIS=0.0                                                        EAM16900
      FSPDO=0.0                                                         EAM16910
      NNOIS=0                                                           EAM16920
      SSNOIS=0.0                                                        EAM16930
C     CALCULATE FIGURE SENSOR FILTER PARAMETERS                         EAM16940
      IF( FSTFLT)2005,2005,2004                                         EAM16950
 2004 DA=-DT/FSTFLT                                                     EAM16960
      FSPHI=EXP( DA)                                                    EAM16970
      GO TO 2006                                                        EAM16980
 2005 FSPHI=0.0                                                         EAM16990
 2006 FSGAM=1.0-FSPHI                                                   EAM17000
      PRINT 1001,FSPHI,FSGAM                                            EAM17010
      RETURN                                                            EAM17020
C                                                                       EAM17030
C     SAMPLE FIGURE SENSOR FILTER OUTPUT                                EAM17040
C     TRANSFER FIGURE ERROR TO SIGMA 2 SOFTWARE                         EAM17050
 3    QXF=FSFLTO                                                        EAM17060
      DOMV( 14)=FSFLTO                                                  EAM17070
      DOMV( 12)=XFAV( I)                                                EAM17080
      RETURN                                                            EAM17090
C                                                                       EAM17100
C     CALL TO FSMDL AT THE END OF EACH FIGURE MEASUREMENT               EAM17110
 4    CONTINUE                                                          EAM17120
C     CALCULATE THE FIGURE SENSOR ERROR                                 EAM17130
      DOMV( 15)=DOMV( 4)-XFAV( I)                                       EAM17140
      RETURN                                                            EAM17150
C                                                                       EAM17160
C     CALL TO FSMDL EVERY DT                                            EAM17170
 5    CONTINUE                                                          EAM17180
C     CALCULATE NEW NOISE INPUT                                         EAM17190
      CALL GAUSS( IRAND,FSNSIG,0.0,FSNOIS)                              EAM17200
C     ADD NOISE TO THE ACTUAL VALUE OF FIGURE ERROR                     EAM17210
      DA=XFAV( I)+FSNOIS                                                EAM17220
C     CALCULATE THE STANDARD DEVIATION OF THE FIGURE SENSOR NOISE       EAM17230
      SSNOIS=SSNOIS+FSNOIS*FSNOIS                                       EAM17240
      NNOIS=NNOIS+1                                                     EAM17250
      DOMV( 17)=SQRT( SSNOIS/NNOIS)                                     EAM17260
      DOMV( 18)=FSNOIS                                                  EAM17270
C     USE A LINEAR FIGURE SENSOR MODEL IF MODV( 3)=1                    EAM17280
      IGO=MODV( 3)                                                      EAM17290
      GO TO( 2000,2003),IGO                                             EAM17300
C     CALCULATE PHASE DETECTOR OUTPUT                                   EAM17310
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 2003 IF(DA*SGN(DA)-0.25)2000,2000,2001                                    EAM17320
 2001 FSPDO=DA-0.50*SGN(DA)                                                EAM17330
      GO TO 2002                                                           EAM17340
 2000 FSPDO=DA                                                             EAM17350
C     FILTER THE PHASE DETECTOR OUTPUT                                     EAM17360
 2002 FSFLTO=FSPHI*FSFLTO+FSGAM*FSPDO                                      EAM17370
C     GENERATE XV FOR PLOTTING RESULTS                                     EAM17380
      IGO=MODV(7)                                                          EAM17390
      GO TO(2200,2201),IGO                                                 EAM17400
C     FIGURE SENSOR DEVELOPMENT                                            EAM17410
C     XFACT                                                                EAM17420
 2200 XV(1)=DOMV(12)                                                       EAM17430
C     XFMEAS                                                               EAM17440
      XV(2)=DOMV(4)                                                        EAM17450
C     FSERR                                                                EAM17460
      XV(3)=DOMV(15)                                                       EAM17470
C     FSOUT                                                                EAM17480
      XV(4)=DOMV(14)                                                       EAM17490
C     XFMN                                                                 EAM17500
      XV(5)=DOMV(1)                                                        EAM17510
C     XFSIG                                                                EAM17520
      XV(6)=DOMV(2)                                                        EAM17530
C     AMBIG                                                                EAM17540
      XV(7)=DOMV(3)                                                        EAM17550
C     XFSW                                                                 EAM17560
      XV(8)=DOMV(5)                                                        EAM17570
C     FSNOIS                                                               EAM17580
      XV(9)=DOMV(18)                                                       EAM17590
      RETURN                                                               EAM17600
C     EAM CONTROL SYSTEM DEVELOPMENT                                       EAM17610
C     PINDEX                                                               EAM17620
 2201 XV(1)=DOMV(13)                                                       EAM17630
C     RPINDEX                                                              EAM17640
      XV(2)=DOMV(19)                                                       EAM17650
C     FSPINDEX                                                             EAM17660
      XV(3)=DOMV(16)                                                       EAM17670
C     XFV(SEE STATEMENT 2301)                                              EAM17680
C     UFAV,UFV                                                             EAM17690
      DO 2202 J=1,NR                                                       EAM17700
      K=J+IB                                                               EAM17710
      XV(K)=UFAV(J)                                                        EAM17720
      L=K+NR                                                               EAM17730
 2202 XV(L)=UFV(J)                                                         EAM17740
      DO 2203 J=7,11                                                       EAM17750
 2203 DOMV(J)=QDUMVA(J)                                                    EAM17760
      RETURN                                                               EAM17770
C                                                                          EAM17780
C     CALL TO FSMSL AT THE END OF EACH COMPLETE SET OF MEASUREMENTS        EAM17790
    6 CONTINUE                                                             EAM17800
C     CALCULATE AND STORE THE PERFORMANCE INDEX                            EAM17810
      CALL PINDX(3,PINDEX,XFV)                                             EAM17820
      DOMV(13)=PINDEX                                                      EAM17830
C     CALCULATE THE FIGURE SENSOR PERFORMANCE INDEX                        EAM17840
      DOMV(16)=0.0                                                         EAM17850
      DO 2300 J=1,N                                                        EAM17860
      DA=XFV(J)-XFAV(J)                                                    EAM17870
 2300 DOMV(16)=DOMV(16)+DA*DA                                              EAM17880
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      DOMV(16)=DOMV(16)/N                                               EAM17890
      DOMV(16)=SQRT(DOMV(16))                                           EAM17900
C     CALCULATE THE TRUE VALUE OF THE PERFORMANCE INDEX                 EAM17910
      CALL PINDX(3,DOMV(19),XFAV)                                       EAM17920
      GO TO(2302,2301),IPLOT                                            EAM17930
      GO TO(2302,2301),IPLOT                                            EAM17930
C     STORE XFV FOR PLOTTING                                            EAM17940
 2301 DO 2303 J=1,N                                                     EAM17950
      K=J+3                                                             EAM17960
 2303 XV(K)=XFV(J)                                                      EAM17970
 2302 RETURN                                                            EAM17980
C                                                                       EAM17990
      END                                                               EAM18000




      SUBROUTINE MAINA(NENTRY)                                          EAM18010
C                                                                       EAM18020
C     SUPERVISORY PROGRAM FOR THE EXPERIMENTAL ACTIVE MIRROR            EAM18030
C     RESIDENT IN THE SIGMA 5 COMPUTER                                  EAM18040
C                                                                       EAM18050
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START                         EAM18060
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),         EAM18070
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),         EAM18080
     2 GAINM(1600),ASV(3)                                               EAM18090
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,     EAM18100
     1 DUMVA,GAINV,GAINM,ASV                                            EAM18110
C                                                                       EAM18120
      DIMENSION LACTV(20)                                               EAM18130
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM18140
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM18150
C                                                                       EAM18160
      DIMENSION AM(400),AIM(400)                                        EAM18170
      COMMON/BLKMFC/AM,AIM                                              EAM18180
C                                                                       EAM18190
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                EAM18200
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),            EAM18210
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),      EAM18220
     3 MODV(20)                                                         EAM18230
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM18240
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM18250
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM18260
C                                                                       EAM18270
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)             EAM18280
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM18290
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END                           EAM18300
C                                                                       EAM18310
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM18320
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM18330
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM18340
     2 QASV(3)                                                          EAM18350
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM18360
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM18370
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM18380
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM18390
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM18400
C                                                                       EAM18410
      DIMENSION DUMVC(20),MSEQV(20)                                     EAM18420
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C                                                                       EAM18430
 1000 FORMAT( 6H MAINA)                                                 EAM18440
 1001 FORMAT( /,37H EAM FIGURE CONTROL SYSTEM PARAMETERS,/)             EAM18450
 1002 FORMAT( /,35H EAM FIGURE ERROR FILTER PARAMETERS,/)               EAM18460
 1003 FORMAT( /,20H HARDWARE MODEL DATA,/)                              EAM18470
 1004 FORMAT( /,23H PERFORMANCE INDEX DATA,/)                           EAM18480
 1011 FORMAT( 1H1)                                                      EAM18490
 1201 FORMAT( 10X,5HTSENS,10X,5HTWAIT,11X,4HTPOS,10X,5HTMINT,10X,5HTMEAS,EAM18500
     1 4X,11HTMEAS/TSENS)                                               EAM18510
 1400 FORMAT( 10X,5HNSENS,10X,5HNWAIT,11X,4HNPOS,10X,5HNMINT,10X,5HNMEAS,EAM18520
     1 9X,6HNFSENS,10X,5HNTIMS)                                         EAM18530
 1401 FORMAT( 7I15)                                                     EAM18540
 1402 FORMAT( 11X,4HGAIN,/,F15.6)                                       EAM18550
C                                                                       EAM18560
      GO TO( 1,2,3,3,5,6,7),NENTRY                                      EAM18570
C                                                                       EAM18580
C     INPUT DATA                                                        EAM18590
 1    PRINT 1000                                                        EAM18600
C                                                                       EAM18610
C     READ DATA FOR THE SIGMA 2 SOFTWARE                                EAM18620
      PRINT 1001                                                        EAM18630
      CALL IRANDP( 6,NTIMSO,NWAIT,NPOS,NMINT,NMEAS,NTYO,IA,4)           EAM18640
      CALL RANDPD( 6,DT,DTE,GAINV( 1),QGA,QGB,UFMAX,DA,4)               EAM18650
      PRINT 1002                                                        EAM18660
      CALL RANDPD( 2,SIGLIM,SLPMN,DA,DA,DA,DA,DA,4)                     EAM18670
      CALL IMXRNP( MSEQV,1,N,4)                                         EAM18680
      PRINT 1003                                                        EAM18690
      CALL FSMDL( 1,I)                                                  EAM18700
      CALL ACTMDL( 1,I)                                                 EAM18710
      CALL MIRMDL( 1,I)                                                 EAM18720
      CALL MIRMDL( 2,I)                                                 EAM18730
C     READ DATA FOR MAINB AND MAINC                                     EAM18740
      CALL MAINB( 1)                                                    EAM18750
      CALL MAINC( 1)                                                    EAM18760
C                                                                       EAM18770
      PRINT 1004                                                        EAM18780
      CALL PINDX( 1,PINDEX,XFV)                                         EAM18790
      FSCALE=FSCALV( 1)                                                 EAM18800
      GO TO 2206                                                        EAM18810
C                                                                       EAM18820
C     INITIALIZATION                                                    EAM18830
 2    CONTINUE                                                          EAM18840
      DUMV( 2)=NWAIT*DT                                                 EAM18850
      DUMV( 3)=NPOS*DT                                                  EAM18860
      DUMV( 4)=NMINT*DT                                                 EAM18870
      DUMV( 5)=DUMV( 2)+N*( DUMV( 3)+NMEAS*DUMV( 4))                    EAM18880
      NFSENS=NWAIT+N*( NPOS+NMEAS*NMINT)                                EAM18890
      NSENS=NFSENS                                                      EAM18900
      DUMV( 1)=NSENS*DT                                                 EAM18910
      TSENS=DUMV( 1)                                                    EAM18920
      DUMV( 6)=DUMV( 5)/DUMV( 1)                                        EAM18930
C     PRINT OUT THE CONTROL SYSTEM TIMING CHARACTERISTICS               EAM18940
      PRINT 1201                                                        EAM18950
      CALL MXRNP( DUMV,1,6,3)                                           EAM18960
C     MULTIPLY GAIN BY TSENS TO MAKE THE DYNAMIC RESPONSE INDEPENDENT   EAM18970
C     OF TSENS                                                          EAM18980
      GAINV( 1)=GAINV( 1)*TSENS                                         EAM18990
C     DIGITAL FILTER INITIALIZATION                                     EAM19000
      AMBIG=0.0                                                         EAM19010
      SXFMN=0.0                                                         EAM19020
      XFLAST=0.0                                                        EAM19030
      XFMN=0.0
      XFSIG=0.0
      XFSW=0.0
C
C     CONTROL SYSTEM INITIALIZATION
      DO 2201 I=1,N
      XFV(I)=0.0
      XFRV(I)=0.0
      DUMV(I)=0.0
      DUMVA(I)=0.0
 2201 DUMVC(I)=0.0
      CALL FSMDL(6,I)
      DO 2203 I=1,20
 2203 DUMV(I)=0.0
C
C     PRINT IMPORTANT PARAMETER VALUES FOR CURRENT RUN
      PRINT 1400
      PRINT 1401,NFSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS
      PRINT 1402,GAINV(1)
C
C
C     INITIALIZE HARDWARE MODELS
      CALL ACTMDL(2,I)
      CALL MIRMDL(2,I)
C     INITIALIZE THE PERFORMANCE INDEX GENERATOR
      CALL PINDX(2,PINDEX,XFV)
C
C     TRANSFER DATA TO THE SIGMA 2 SOFTWARE
 2206 QDT=DT
      QDTE=DTE
      QUFMAX=UFMAX*ASCALV(1)
      NQ=N
      NRQ=NR
      DO 2204 I=1,N
      QXFSV(I)=XFSV(I)*PSCALE
      QYFSV(I)=YFSV(I)*PSCALE
      MSEQVQ(I)=MSEQV(I)
      QDUMVA(I)=0.0
      QDUMVB(I)=0.0
 2204 QDUMVC(I)=0.0
      DO 2205 I=1,NR
      UFV(I)=0.0
      UFAV(I)=0.0
      QUFV(I)=0.0
 2205 QUFAV(I)=0.0
      NSENSQ=NSENS
      NWAITQ=NWAIT
      NPOSQ=NPOS
      NMINTQ=NMINT
      NMEASQ=NMEAS
      NFSENQ=NFSENS
      NTIMS=NTIMSO
      NTIMSQ=NTIMS
      ITYO=0
      FSCALE=FSCALV(1)
      RETURN
C
C     OPERATION
 3    RETURN
C
C     CALCULATE FIGURE CONTROLS
C
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C     CALCULATE THE INITIAL ALIGNMENT CONTROLS IF MODV(4)=1             EAM19650
 5    IGO=MODV(4)                                                       EAM19660
      GO TO(2501,2502),IGO                                              EAM19670
 2501 CALL MAINC(3)                                                     EAM19680
      RETURN                                                            EAM19690
C                                                                       EAM19700
C     GENERATE XFRV                                                     EAM19710
 2502 CONTINUE                                                          EAM19720
      J=0                                                               EAM19730
      DO 2506 I=1,N                                                     EAM19740
      GO TO (2508,2509,2509),MODOP                                      EAM19750
 2508 IF(LACTV(I))2507,2506,2507                                        EAM19760
 2507 J=J+1                                                             EAM19770
      XFRV(J)=XFV(I)                                                    EAM19780
      GO TO 2506                                                        EAM19790
 2509 XFRV(I)=XFV(I)                                                    EAM19800
 2506 CONTINUE                                                          EAM19810
C                                                                       EAM19820
C     DUMVC=GAINM*XFRV                                                  EAM19830
      CALL MPRD(GAINM,XFRV,DUMVC,NR,NRA,0,0,1)                          EAM19840
C     DUMVC=DUMVC*GAINV(1)                                              EAM19850
      DO 2510 I=1,NR                                                    EAM19860
 2510 DUMVC(I)=DUMVC(I)*GAINV(1)                                        EAM19870
C     INTEGRAL COMPENSATION                                             EAM19880
C     UFV=DUMVC+UFV                                                     EAM19890
      DO 2520 I=1,NR                                                    EAM19900
      UFV(I)=DUMVC(I)+UFV(I)                                            EAM19910
 2520 QUFV(I)=UFV(I)*ASCALV(I)                                          EAM19920
C*****EAM SOFTWARE TEST CODING******************************************EAM19930
C     STORE IMPORTANT PARAMETERS IN FSMDL AT TERMINATION OF             EAM19940
C     MEASUREMENT SEQUENCE                                              EAM19950
      CALL FSMDL(6,LSENS)                                               EAM19960
C*****EAM SOFTWARE TEST CODING******************************************EAM19970
C     PRINT OUTPUT DATA ON REMOTE IO DEVICE EVERY NTYO TIMES            EAM19980
C     THE CONTROL IS COMPUTED                                           EAM19990
      ITYO=ITYO-1                                                       EAM20000
      IF(ITYO)2521,2521,2522                                            EAM20010
 2521 ITYO=NTYO                                                         EAM20020
      NFLGC=2                                                           EAM20030
      CALL PINDX(3,QDUMVA(1),XFV)                                       EAM20040
 2522 RETURN                                                            EAM20050
C                                                                       EAM20060
C     DIGITAL FILTER FOR FIGURE SENSOR OUTPUTS                          EAM20070
C                                                                       EAM20080
 6    GO TO 2703                                                        EAM20090
 2702 IF(XFSIG-SIGLIM)2332,2332,2331                                    EAM20100
C     FIGURE ERROR COMPUTATION IF XFSIG IS LESS THAN SIGLIM             EAM20110
C     CORRECT FIGURE ERROR FOR AMBIGUITY                                EAM20120
 2332 XFV(LSENS)=XFMN+AMBIG                                             EAM20130
C     CALCULATE THE NEAREST SWITCHING BOUNDARY                          EAM20140
      XFSW=0.25*SGN(XFLAST)                                             EAM20150
C     STORE CURRENT VALUE OF XF                                         EAM20160
      XFLAST=XFV(LSENS)                                                 EAM20170
      GO TO 2360                                                        EAM20180
C     FIGURE ERROR COMPUTATION IF XFSIG IS GREATER THAN SIGLIM          EAM20190
 2331 XFV(LSENS)=XFSW-SLPMN*XFMN                                        EAM20200
C     CALCULATE AMBIGUITY FACTOR                                        EAM20210
      IF(SGN(XFMN*SXFMN))2353,2353,2360                                 EAM20220
 2353 AMBIG=AMBIG+SGN(SXFMN)*0.50                                       EAM20230
 2360 CONTINUE                                                          EAM20240
C     STORE IMPORTANT PARAMETERS IN DUMV FOR FURTHER USE IN OTHER ROUTINEAM20250
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      DUMV( 1)=XFMN                                                     EAM20260
      DUMV( 2)=XFSIG                                                    EAM20270
      DUMV( 3)=AMBIG                                                    EAM20280
      DUMV( 4)=XFV(LSENS)                                               EAM20290
      DUMV( 5)=XFSW                                                     EAM20300
      DUMV( 6)=XFLAST                                                   EAM20310
C     STORE LAST VALUE OF XFMN                                          EAM20320
      SXFMN=XFMN                                                        EAM20330
C*****EAM SOFTWARE TEST CODING*******************************************EAM20340
      CALL FSMDL(4,LSENS)                                               EAM20350
C*****EAM SOFTWARE TEST CODING*******************************************EAM20360
C     MODV(7)=1 FOR FIGURE SENSOR TEST, 2 FOR MIRROR FIGURE CONTROL    MEAM20370
      IGO=MODV(7)                                                       EAM20380
      GO TO(2704,2705),IGO                                              EAM20390
 2704 RETURN                                                            EAM20400
C                                                                       EAM20410
C     CALCULATE THE FIGURE ERRORS AT THE TERMINATION OF ALL MEASUREMENTSEAM20420
C     IF THE MIRROR FIGURE CONTROL MODE IS SELECTED I.E. MODV(7)=2      EAM20430
 7    MSENS=N+1                                                         EAM20440
      IGO=MODV(7)                                                       EAM20450
      GO TO(2700,2705),IGO                                              EAM20460
 2700 RETURN                                                            EAM20470
C                                                                       EAM20480
 2705 MSENS=MSENS-1                                                     EAM20490
      IF(MSENS)2700,2700,2701                                           EAM20500
 2701 LSENS=MSEQV(MSENS)                                                EAM20510
C     CALCULATE XFMN AND XFSIG AT ALL THE MEASUREMENT POINTS            EAM20520
 2703 XFMN=QDUMVB(LSENS)*FSCALE                                         EAM20530
      XFSIG=QDUMVC(LSENS)*FSCALE*FSCALE                                 EAM20540
      XFSIG=XFSIG-XFMN*XFMN                                             EAM20550
      XFMN=XFMN/NMEAS                                                   EAM20560
      XFSIG=XFSIG/NMEAS                                                 EAM20570
      XFSIG=SQRT(XFSIG)                                                 EAM20580
C     TRANSFER TO THE DIGITAL FIGURE ERROR FILTER                       EAM20590
C     SKIP FILTERING IF MODV(4)=1                                       EAM20600
      IGO=MODV(4)                                                       EAM20610
      GO TO(2360,2702),IGO                                              EAM20620
C                                                                       EAM20630
      END                                                               EAM20640
      SUBROUTINE MAINB(NENTRY)                                          EAM20650
C                                                                       EAM20660
C     SUBROUTINE FOR TYPEWRITER CONTROL OF THE EXPERIMENTAL ACTIVE      EAM20670
C     MIRROR                                                            EAM20680
C                                                                       EAM20690
C     SIGMA 5 TYPE C DIMENSION STATEMENTS START                         EAM20700
      DIMENSION XV(1813)                                                EAM20710
      COMMON/BLKEAM/XV                                                  EAM20720
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),         EAM20730
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),         EAM20740
     2 GAINM(1600),ASV(3)                                               EAM20750
      EQUIVALENCE (XV(1),XFV(1)),(XV(21),UFV(1)),(XV(41),ASCALV(1)),    EAM20760
     1 (XV(61),FSCALV(1)),(XV(81),XFSV(1)),(XV(101),YFSV(1)),           EAM20770
     2 (XV(121),XFRV(1)),(XV(141),DUMV(1)),(XV(161),UFAV(1)),           EAM20780
     3 (XV(181),DUMVA(1)),(XV(201),GAINV(1)),(XV(211),GAINM(1)),        EAM20790
     4 (XV(1811),ASV(1))                                                EAM20800
C                                                                       EAM20810
      DIMENSION LACTV(20)                                               EAM20820
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM20830
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM20840
C                                                                       EAM20850
      DIMENSION AM(400),AIM(400)                                        EAM20860
      COMMON/BLKMFC/AM,AIM                                              EAM20870
C                                                                       EAM20880
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                EAM20890
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),            EAM20900
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),      EAM20910
     3 MODV(20)                                                         EAM20920
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM20930
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM20940
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM20950
C                                                                       EAM20960
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)             EAM20970
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM20980
C     SIGMA 5 TYPE C DIMENSION STATEMENTS END                           EAM20990
C                                                                       EAM21000
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM21010
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM21020
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM21030
     2 QASV(3)                                                          EAM21040
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM21050
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM21060
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM21070
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM21080
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM21090
C                                                                       EAM21100
      DIMENSION NAMV(17)                                                EAM21110
C                                                                       EAM21120
      DATA NAMV(1),NAMV(2),NAMV(3),NAMV(4),NAMV(5),NAMV(6),NAMV(7),     EAM21130
     1 NAMV(8),NAMV(9),NAMV(10),NAMV(11),NAMV(12),NAMV(13),NAMV(14),    EAM21140
     2 NAMV(15),NAMV(16),NAMV(17)                                       EAM21150
     3 /4HXV  ,4HAM  ,4HAIM ,4HXFV ,4HXFRV,4HUFV ,4HUFAV,4HASCV,        EAM21160
     4 4HFSCV,4HXFSV,4HYFSV,4HDUMV,4HGANM,4HGANV,4HLACV,4HMDVQ,4HDEND/  EAM21170
C                                                                       EAM21180
 1000 FORMAT(6H MAINB)                                                  EAM21190
C                                                                       EAM21200
      GO TO(1,2,3,4,5,6),NENTRY                                         EAM21210
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C                                                                        EAM21220
C     INPUT DATA                                                         EAM21230
 1    PRINT 1000                                                         EAM21240
      NNAMV=17                                                           EAM21250
      RETURN                                                             EAM21260
C                                                                        EAM21270
C     INITIALIZATION                                                     EAM21280
 2    RETURN                                                             EAM21290
C                                                                        EAM21300
C     CATALOG AND CHECK INPUT NAME FROM TYPCON                           EAM21310
 3    DO 2302 I=1,NNAMV                                                  EAM21320
      IF( NFLGC-NAMV( I))2302,2301,2302                                  EAM21330
 2301 LL=I                                                               EAM21340
      GO TO 2303                                                         EAM21350
 2302 CONTINUE                                                           EAM21360
C     SUBMITTED NAME NOT IN CATALOG                                      EAM21370
      NFLGC=3                                                            EAM21380
      CALL MARK( 1,24,4,4,3)                                             EAM21390
C     CALL TYPCON( 4) AND RETURN THROUGH MAINB(3)                        EAM21400
      RETURN                                                             EAM21410
C                                                                        EAM21420
C     IDENTIFY THE NUMBER OF INDICES                                     EAM21430
 2303 GO TO ( 2310,2320,2320,2310,2310,2310,2310,2310,2310,2310,2310,    EAM21440
     1 2310,2320,2310,2310,2310,2304),LL                                 EAM21450
C                                                                        EAM21460
C     REQUEST NEW MODE IF NFLGC=4HDEND                                   EAM21470
 2304 NFLGC=4                                                            EAM21480
      RETURN                                                             EAM21490
C                                                                        EAM21500
C     RETURN TO SIGMA 2 TO REQUEST INDEX VALUES                          EAM21510
 2310 NFLGC=1                                                            EAM21520
      CALL MARK( 1,24,5,4,4)                                             EAM21530
      RETURN                                                             EAM21540
C     CALL TYPCON( 5) AND RETURN THROUGH MAINB( 4)                       EAM21550
C                                                                        EAM21560
 2320 NFLGC=2                                                            EAM21570
      CALL MARK( 1,24,6,4,4)                                             EAM21580
      RETURN                                                             EAM21590
C     CALL TYPCON( 6) AND RETURN THROUGH MAINB( 4)                       EAM21600
C                                                                        EAM21610
C     MODIFY AND/OR EXTRACT THE VALUE OF THE INTERROGATED VARIABLE       EAM21620
 4    V=QDUMVA( 1)                                                       EAM21630
      II=NFLGD                                                           EAM21640
      JJ=NFLGE                                                           EAM21650
      ICHNG=NFLGC                                                        EAM21660
      GO TO ( 2401,2402,2403,2404,2405,2406,2407,2408,2409,2410,2411,    EAM21670
     1 2412,2413,2414,2415,2416,2417),LL                                 EAM21680
 2401 CALL CHNG( ICHNG,V,XV( II))                                        EAM21690
      V=XV( II)                                                          EAM21700
      GO TO 2500                                                         EAM21710
 2402 CALL ELMA( ICHNG,AM,II,JJ,V,NR)                                    EAM21720
      CALL ELMA( 2,AM,II,JJ,V,NR)                                        EAM21730
      GO TO 2500                                                         EAM21740
 2403 CALL ELMA( ICHNG,AIM,II,JJ,V,NR)                                   EAM21750
      CALL ELMA( 2,AIM,II,JJ,V,NR)                                       EAM21760
      GO TO 2500                                                         EAM21770
 2404 CALL CHNG( ICHNG,V,XFV( II))                                       EAM21780
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      V=XFV(II)                                                         EAM21790
      GO TO 2500                                                        EAM21800
 2405 CALL CHNG(ICHNG,V,XFRV(II))                                       EAM21810
      V=XFRV(II)                                                        EAM21820
 2406 CALL CHNG(ICHNG,V,UFV(II))                                        EAM21830
      V=UFV(II)                                                         EAM21840
      GO TO 2500                                                        EAM21850
 2407 CALL CHNG(ICHNG,V,UFAV(II))                                       EAM21860
      V=UFAV(II)                                                        EAM21870
      GO TO 2500                                                        EAM21880
 2408 CALL CHNG(ICHNG,V,ASCALV(II))                                     EAM21890
      V=ASCALV(II)                                                      EAM21900
      GO TO 2500                                                        EAM21910
 2409 CALL CHNG(ICHNG,V,FSCALV(II))                                     EAM21920
      V=FSCALV(II)                                                      EAM21930
      GO TO 2500                                                        EAM21940
 2410 CALL CHNG(ICHNG,V,XFSV(II))                                       EAM21950
      V=XFSV(II)                                                        EAM21960
      GO TO 2500                                                        EAM21970
 2411 CALL CHNG(ICHNG,V,YFSV(II))                                       EAM21980
      V=YFSV(II)                                                        EAM21990
      GO TO 2500                                                        EAM22000
 2412 CALL CHNG(ICHNG,V,DUMV(II))                                       EAM22010
      V=DUMV(II)                                                        EAM22020
      GO TO 2500                                                        EAM22030
 2413 CALL ELMA(ICHNG,GAINM,II,JJ,V,NR)                                 EAM22040
      CALL ELMA(2,GAINM,II,JJ,V,NR)                                     EAM22050
      GO TO 2500                                                        EAM22060
 2414 CALL CHNG(ICHNG,V,GAINV(II))                                      EAM22070
      V=GAINV(II)                                                       EAM22080
      GO TO 2500                                                        EAM22090
 2415 V=LACTV(II)                                                       EAM22100
      GO TO 2500                                                        EAM22110
 2416 V=MODVQ(II)                                                       EAM22120
      GO TO 2500                                                        EAM22130
 2417 RETURN                                                            EAM22140
C                                                                       EAM22150
 2500 QDUMVA(1)=V                                                       EAM22160
      RETURN                                                            EAM22170
C                                                                       EAM22180
C     CALCULATE AND TRANSFER THE VALUE OF THE PERFORMANCE INDEX         EAM22190
C     TO THE SIGMA 2                                                    EAM22200
 5    CALL PINDX(3,QDUMVA(1),XFV)                                       EAM22210
      RETURN                                                            EAM22220
C     RETURN TO TYPCON(3)                                               EAM22230
C                                                                       EAM22240
 6    RETURN                                                            EAM22250
      END                                                               EAM22260
      SUBROUTINE MAINC(NENTRY)
C
C     SUBROUTINE TO CALCULATE INITIAL ALIGNMENT CONTROLS
C
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),
     2 GAINM(1600),ASV(3)
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,
     1 DUMVA,GAINV,GAINM,ASV
C
      DIMENSION LACTV(20)
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS
C
      DIMENSION AM(400),AIM(400)
      COMMON/BLKMFC/AM,AIM
C
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),
     3 MODV(20)
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,
     2 NMCXV,NMCPV,NMICPV,MODV
C
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END
C
C     SIGMA 2 DIMENSION STATEMENTS START
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),
     2 QASV(3)
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ
C     SIGMA 2 DIMENSION STATEMENTS END
C
      DIMENSION NHCV(2),NICV(2),SXFSV(9),SYFSV(9),SUFV(9),DELUV(2),
     1 SASV(3),LREFAV(9),SMXV(9),SMYV(9)
C
 1000 FORMAT(' MAINC')
 1001 FORMAT(/,' INITIAL ALIGNMENT CONTROL SYSTEM DATA')
 1002 FORMAT(/,' AMBIGUITY SENSOR MODEL DATA')
 1003 FORMAT(/,' SLEW CONTROL SYSTEM DATA')
 1004 FORMAT(/,' TILT CONTROL SYSTEM DATA')
 1005 FORMAT(/,' POSITION ACTUATOR DATA')
C
      GO TO(1,2,3),NENTRY
C
C     INPUT DATA
 1    PRINT 1000
      PRINT 1001
C     READ ACTUATOR INDICES
      CALL IMXRNP(LREFAV,1,9,4)
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C     READ ACTUATOR POSITIONS                                           EAM22840
      CALL MXRNP(SMXV,1,9,4)                                            EAM22850
      CALL MXRNP(SMYV,1,9,4)                                            EAM22860
C     READ AMBIGUITY SENSOR MODEL DATA                                  EAM22870
      PRINT 1002                                                        EAM22880
      CALL RANDPD(3,BSMP,BSDP,DELU,DA,DA,DA,DA,4)                       EAM22890
C     READ SLEW CONTROL SYSTEM DATA                                     EAM22900
      PRINT 1003                                                        EAM22910
      CALL IRANDP(2,NHM,NIM,IA,IA,IA,IA,IA,4)                           EAM22920
C     READ TILT CONTROL SYSTEM DATA                                     EAM22930
      PRINT 1004                                                        EAM22940
      CALL IRANDP(2,NTILT,NCTILT,IA,IA,IA,IA,IA,4)                      EAM22950
      CALL RANDPD(1,GTILT,DA,DA,DA,DA,DA,DA,4)                          EAM22960
C     READ POSITION ACTUATOR DATA                                       EAM22970
      PRINT 1005                                                        EAM22980
      CALL IRANDP(1,NCVEL,IA,IA,IA,IA,IA,IA,4)                          EAM22990
      NCVELQ=NCVEL                                                      EAM23000
      INITL=1                                                           EAM23010
      RETURN                                                            EAM23020
C                                                                       EAM23030
C     INITIALIZATION                                                    EAM23040
 2    INITL=2                                                           EAM23050
C     SET ALL CONTROLS TO ZERO                                          EAM23060
      DO 2100 I=1,NR                                                    EAM23070
      UFV(I)=0.0                                                        EAM23080
      QUFV(I)=0.0                                                       EAM23090
 2100 SUFV(I)=0.0                                                       EAM23100
C     TILT CONTROL SYSTEM INITIALIZATION                                EAM23110
      ITILT=0                                                           EAM23120
      JTILT=0                                                           EAM23130
      MDTILT=1                                                          EAM23140
C     CALCULATE TILT MEASUREMENT POSITION INCREMENT                     EAM23150
      DC=1.0/NTILT                                                      EAM23160
C     SLEW CONTROL SYSTEM INITIALIZATION                                EAM23170
      DO 2101 I=1,2                                                     EAM23180
      NICV(I)=0                                                         EAM23190
      NHCV(I)=0                                                         EAM23200
      SASV(I)=0.0                                                       EAM23210
 2101 DELUV(I)=DELU                                                     EAM23220
C     STORE N AND REPLACE IT WITH NEW VALUE                             EAM23230
      NS=N                                                              EAM23240
      N=9                                                               EAM23250
C     STORE XFSV AND YFSV IN SXFSV AND SYFSV                            EAM23260
      CALL MCPY(XFSV,SXFSV,1,9,0)                                       EAM23270
      CALL MCPY(YFSV,SYFSV,1,9,0)                                       EAM23280
C     SET THE FIRST NINE ELEMENTS OF XFSV AND YFSV TO THE ACTUATOR      EAM23290
C     POSITIONS                                                         EAM23300
      CALL MCPY(SMXV,XFSV,1,9,0)                                        EAM23310
      CALL MCPY(SMYV,YFSV,1,9,0)                                        EAM23320
C                                                                       EAM23330
 3    GO TO(2,2409),INITL                                               EAM23340
 2409 IGO=MODV(5)                                                       EAM23350
      GO TO(2410,2420),IGO                                              EAM23360
C                                                                       EAM23370
C     TILT CONTROL SYSTEM                                               EAM23380
 2410 GO TO(2310,2320),MDTILT                                           EAM23390
C                                                                       EAM23400
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C      CALCULATE CONTROLS TO SET REFERENCE POSITION ERRORS TO ZERO
 2310 ITILT=ITILT+1
      IF( ITILT-NCTILT)2311,2311,2313
 2311 J=1
      DO 2312 I=1,3
      K=LREFAV( J)
      SUFV( K)=SUFV( K)+GTILT*( XFV( K))
      UFV( K)=SUFV( K)
      QUFV( K)=UFV( K)*ASCALV( K)
 2312 J=J+3
      RETURN
 2313 MDTILT=2
      ITILT=1
      GO TO 2482
C
C      CALCULATE CONTROLS TO SET SECONDARY POSITION ERRORS TO ZERO
 2320 ITILT=ITILT+1
      IF( ITILT-NCTILT)2481,2481,2482
 2482 JTILT=JTILT+1
      IF( JTILT-NTILT)2483,2483,2484
C      INCREMENT MEASUREMENT POSITIONS
 2483 DB=DB+DC
      DA=1.0-DB
      ITILT=0
      J=1
      DO 2480 I=1,3
      K=J+1
      L=J+2
      XFSV( K)=XFSV( J)*DA+SMXV( K)*DB
      YFSV( K)=YFSV( J)*DA+SMYV( K)*DB
      XFSV( L)=XFSV( J)*DA+SMXV( L)*DB
      YFSV( L)=YFSV( J)*DA+SMYV( L)*DB
 2480 J=J+3
C      CALCULATE THE CONTROLS TO SET THE TILT TO ZERO
 2481 J=1
      DO 2490 I=1,3
      K=J+1
      L=J+2
      IA=LREFAV( K)
      IB=LREFAV( L)
      SUFV( IA)=SUFV( IA)+GTILT*XFV( K)
      UFV( IA)=SUFV( IA)
      QUFV( IA)=UFV( IA)*ASCALV( IA)
      SUFV( IB)=SUFV( IB)+GTILT*XFV( L)
      UFV( IB)=SUFV( IB)
      QUFV( IB)=UFV( IB)*ASCALV( IB)
 2490 J=J+3
      RETURN
C
C      AMBIGUITY SENSOR MODEL
 2420 IGO=MODV( 8)
      GO TO( 2506,2505),IGO
 2506 J=2
      DO 2504 I=1,3
      GO TO( 2501,2502,2503),I
 2501 DA=XFV( 4)-XFV( 1)
      GO TO 2504
 2502 DA=XFV(7)-XFV(1)                                                  EAM23980
      GO TO 2504                                                        EAM23990
 2503 DA=XFV(7)-XFV(4)                                                  EAM24000
 2504 ASV(I)=BSMP-BSDP*DA*DA                                            EAM24010
      GO TO 2507                                                        EAM24020
C                                                                       EAM24030
C     TRANSFER THE AMBIGUITY SENSOR OUTPUTS TO THE SIGMA 5              EAM24040
 2505 CALL MCPY(QASV,ASV,1,3,0)                                         EAM24050
C                                                                       EAM24060
C     SLEW CONTROL SYSTEM                                               EAM24070
 2507 J=4                                                               EAM24080
      DO 2700 I=1,2                                                     EAM24090
      L=J+2                                                             EAM24100
      IF(ASV(I)-SASV(I))2702,2702,2703                                  EAM24110
C     SUCESSFUL ITERATION                                               EAM24120
 2703 NICV(I)=NICV(I)+1                                                 EAM24130
      IGO=1                                                             EAM24140
C     UNSUCESSFUL ITERATION                                             EAM24150
      IF(NICV(I)-NIM)2708,2708,2717                                     EAM24160
 2717 DELUV(I)=0.0                                                      EAM24170
      GO TO 2708                                                        EAM24180
 2702 IGOA=IGOA+1                                                       EAM24190
      GO TO(2706,2707),IGOA                                             EAM24200
C     CHANGE SIGN OF THE CONTROL PERTURBATION                           EAM24210
 2706 DELUV(I)=-DELUV(I)                                                EAM24220
      SASV(I)=ASV(I)                                                    EAM24230
      GO TO 2708                                                        EAM24240
C     REDUCE THE SIZE OF THE CONTROL PERTURBATION                       EAM24250
 2707 DELUV(I)=DELUV(I)/2.0                                             EAM24260
      NHCV(I)=NHCV(I)+1                                                 EAM24270
      IF(NHCV(I)-NHM)2713,2713,2714                                     EAM24280
 2714 DELUV(I)=0.0                                                      EAM24290
      GO TO 2708                                                        EAM24300
 2713 IGOA=1                                                            EAM24310
C     CALCULATE THE SLEW CONTROLS                                       EAM24320
 2708 DO 2710 J=K,L                                                     EAM24330
      IA=LREFAV(K)                                                      EAM24340
      UFV(IA)=DELUV(I)                                                  EAM24350
 2710 QUFV(IA)=UFV(IA)*ASCALV(IA)                                       EAM24360
 2700 J=J+3                                                             EAM24370
C     CHECK TERMINATION CRITERION                                       EAM24380
 5    IF(DELUV(1)*DELUV(2))2715,2484,2715                               EAM24390
 2715 RETURN                                                            EAM24400
C                                                                       EAM24410
C     TERMINATE INITIAL ALIGNMENT                                       EAM24420
 2484 MODEQ=3                                                           EAM24430
      INITL=1                                                           EAM24440
C     RESET N TO ORIGINAL VALUE                                         EAM24450
      N=NS                                                              EAM24460
C     RESET XFSV AND YFSV TO ORIGINAL VALUES                            EAM24470
      CALL MCPY(SXFSV,XFSV,1,9,0)                                       EAM24480
      CALL MCPY(SYFSV,YFSV,1,9,0)                                       EAM24490
      RETURN                                                            EAM24500
C                                                                       EAM24510
      END                                                               EAM24520
      SUBROUTINE MFCS(NENTRY)
C
C     SUBROUTINE TO CALCULATE MIRROR FIGURE CONTROL SYSTEM PARAMETERS
C
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),
     2 GAINM(1600),ASV(3)
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,
     1 DUMVA,GAINV,GAINM,ASV
C
      DIMENSION LACTV(20)
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS
C
      DIMENSION AM(400),AIM(400)
      COMMON/BLKMFC/AM,AIM
C
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),
     3 MODV(20)
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,
     2 NMCXV,NMCPV,NMICPV,MODV
C
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END
C
C     SIGMA 2 DIMENSION STATEMENTS START
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),
     2 QASV(3)
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ
C     SIGMA 2 DIMENSION STATEMENTS END
C
      DIMENSION DUMM(400)
C
 1000 FORMAT(5H MFCS)
 1001 FORMAT(/,11X,4HA*AI)
 1002 FORMAT(/,10X,5HGAINM)
 1003 FORMAT(/,33H SIMPLIFIED LINEAR CONTROL SYSTEM,/)
 1004 FORMAT(/,30H LINEAR OPTIMAL CONTROL SYSTEM,/)
 1005 FORMAT(/,34H GENERALIZED LINEAR CONTROL SYSTEM,/)
 1006 FORMAT(/,7X,8HA*ASCALE)
 1007 FORMAT(/,9X,6HART*AR)
 1008 FORMAT(/,3X,12H(ART*AR)**-1)
 1009 FORMAT(/,19H FIGURE SENSOR DATA,/)
 1010 FORMAT(/,21H FIGURE ACTUATOR DATA,/)
 1011 FORMAT(/,29H CONTROL SYSTEM CONFIGURATION,/)
 1012 FORMAT(/,18H MIRROR MODEL DATA,/)
 1013 FORMAT(/,24H MIRROR CALIBRATION DATA,/)
 1014 FORMAT(/,19H ACTUATOR TEST DATA,/)
 1015 FORMAT(2E10.3)                                                    EAM25100
C                                                                       EAM25110
      GO TO (1,2,3,4,5,6,7),NENTRY                                      EAM25120
C                                                                       EAM25130
C     MIRROR FIGURE CONTROL SYSTEM INPUT DATA                           EAM25140
 1    PRINT 1000                                                        EAM25150
      CALL IRANDP(5,NSNSWT,NTYPI,NTYPO,NPUNCH,NMAG,IA,IA,4)             EAM25160
C                                                                       EAM25170
C     READ BASIC DATA FOR THE EXPERIMENTAL ACTIVE MIRROR                EAM25180
      PRINT 1012                                                        EAM25190
C     N,NR                                                              EAM25200
      CALL IRANDP(2,N,NR,IA,IA,IA,IA,IA,4)                              EAM25210
      NA=N                                                              EAM25220
C     IF MODV(10)=2 READ IN THE REDUCED A MATRIX                        EAM25230
      IGO=MODV(10)                                                      EAM25240
      GO TO(2005,2006),IGO                                              EAM25250
 2006 NA=NR                                                             EAM25260
 2005 CONTINUE                                                          EAM25270
C     AM                                                                EAM25280
      CALL MXRNP(AM,N,NA,4)                                             EAM25290
C     ASCALE                                                            EAM25300
      CALL RANDPD(2,ASCALE,AIMSCL,DA,DA,DA,DA,DA,4)                     EAM25310
      ASCLB=1.0/AIMSCL                                                  EAM25320
      GAINV(7)=ASCALE                                                   EAM25330
C     SCALE THE A MATRIX                                                EAM25340
      IF(ASCALE-1.0)2002,2001,2002                                      EAM25350
 2002 IA=N*NA                                                           EAM25360
      DO 2003 I=1,IA                                                    EAM25370
 2003 AM(I)=AM(I)*ASCALE                                                EAM25380
      PRINT 1006                                                        EAM25390
      CALL MXRNP(AM,N,NA,3)                                             EAM25400
 2001 CONTINUE                                                          EAM25410
      PRINT 1009                                                        EAM25420
C     FSCALE                                                            EAM25430
      CALL RANDPD(1,FSCALE,DA,DA,DA,DA,DA,DA, 4)                        EAM25431
      FSCALV(1)=FSCALE                                                  EAM25432
C     XFSV                                                              EAM25450
      CALL MXRNP(XFSV,1,N,4)                                            EAM25460
C     YFSV                                                              EAM25470
      CALL MXRNP(YFSV,1,N,4)                                            EAM25480
C     PSCALE                                                            EAM25490
      CALL RANDPD(1,PSCALE,DA,DA,DA,DA,DA,DA,4)                         EAM25500
      PRINT 1010                                                        EAM25510
C     LACTV                                                             EAM25520
      CALL IMXRNP(LACTV,1,N,4)                                          EAM25530
C     ASCALV                                                            EAM25540
      CALL MXRNP(ASCALV,1,NR,4)                                         EAM25550
C     GAINV                                                             EAM25560
      PRINT 1011                                                        EAM25570
C     MODOP                                                             EAM25580
      CALL IRANDP(1,MODOP,IA,IA,IA,IA,IA,IA,4)                          EAM25590
      PRINT 1014                                                        EAM25600
      CALL ACTCAL(1)                                                    EAM25610
      PRINT 1013                                                        EAM25620
      CALL MIRCAL(1)                                                    EAM25630
C                                                                       EAM25640
C     CALCULATE FEEDBACK MATRIX                                         EAM25650
 2    GO TO(2110,2120,2130),MODOP                                       EAM25660
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C                                                                       EAM25670
C     SIMPLIFIED LINEAR CONTROL SYSTEM                                  EAM25680
C     GAINM=ARR**-1                                                     EAM25690
C     GENERATE ARR                                                      EAM25700
 2110 NRA=NR                                                            EAM25710
      PRINT 1003                                                        EAM25720
      GO TO( 2111,2112),IAMODE                                          EAM25730
 2111 CALL REDUAM( 1)                                                   EAM25740
 2112 CALL REDUAM( 2)                                                   EAM25750
C     GAINM=ARR**-1                                                     EAM25760
C     SCALE A                                                           EAM25770
      IA=NR*NR                                                          EAM25780
      DO 2113 I=1,IA                                                    EAM25790
 2113 AM( I)=AM( I)*AIMSCL                                              EAM25800
      CALL SINV( NR,AM,GAINM,DUMM,DA)                                   EAM25810
C     SCALE AI                                                          EAM25820
      DO 2114 I=1,IA                                                    EAM25830
      AM( I)=AM( I)*ASCLB                                               EAM25840
 2114 GAINM( I)=GAINM( I)*AIMSCL                                        EAM25850
C     CHECK A*AI=I?                                                     EAM25860
      CALL MPRD( AM,GAINM,AIM,NR,NR,0,0,NR)                             EAM25870
      PRINT 1001                                                        EAM25880
      CALL MXRNP( AIM,NR,NR,3)                                          EAM25890
C                                                                       EAM25900
C     PRINT SLCS GAIN MATRIX                                            EAM25910
      PRINT 1002                                                        EAM25920
      CALL MXRNP( GAINM,NR,NR,3)                                        EAM25930
      RETURN                                                            EAM25940
C                                                                       EAM25950
C     LINEAR OPTIMAL CONTROL SYSTEM                                     EAM25960
C     GAINM=(( ART*AR)**-1)*ART                                         EAM25970
 2120 NRA=N                                                             EAM25980
      PRINT 1004                                                        EAM25990
C     GENERATE AR                                                       EAM26000
      GO TO( 2121,2122),IAMODE                                          EAM26010
 2121 CALL REDUAM( 1)                                                   EAM26020
C     GENERATE ART                                                      EAM26030
 2122 CALL MTRA( AM,AIM,N,NR,0)                                         EAM26040
      CALL MPRD( AIM,AM,GAINM,NR,N,0,0,NR)                              EAM26050
      PRINT 1007                                                        EAM26060
      CALL MXRNP( GAINM,NR,NR,3)                                        EAM26070
C     SCALE A                                                           EAM26080
      IA=NR*NR                                                          EAM26090
      DO 2123 I=1,IA                                                    EAM26100
 2123 GAINM( I)=GAINM( I)*AIMSCL                                        EAM26110
      CALL SINV( NR,GAINM,AM,DUMM,DA)                                   EAM26120
C     SCALE AI                                                          EAM26130
      DO 2124 I=1,IA                                                    EAM26140
      GAINM( I)=GAINM( I)*ASCLB                                         EAM26150
 2124 AM( I)=AM( I)*AIMSCL                                              EAM26160
      PRINT 1008                                                        EAM26170
      CALL MXRNP( AM,NR,NR,3)                                           EAM26180
      CALL MPRD( AM,GAINM,DUMM,NR,NR,0,0,NR)                            EAM26190
      PRINT 1001                                                        EAM26200
      CALL MXRNP( DUMM,NR,NR,3)                                         EAM26210
      CALL MPRD( AM,AIM,GAINM,NR,NR,0,0,N)                              EAM26220
C                                                                       EAM26230
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C     PRINT LOCS GAIN MATRIX                                            EAM26240
      PRINT 1002                                                        EAM26250
      CALL MXRNP(GAINM,NR,N,3)                                          EAM26260
      RETURN                                                            EAM26270
C                                                                       EAM26280
C     GENERALIZED LINEAR CONTROL SYSTEM                                 EAM26290
 2130 NRA=N                                                             EAM26300
      PRINT 1005                                                        EAM26310
      CALL MXRNP(GAINM,NR,N,4)                                          EAM26320
      RETURN                                                            EAM26330
C                                                                       EAM26340
C     EXPERIMENTALLY CHECK ACTUATOR OPERATION                           EAM26350
 3    IGO=MODV(12)                                                      EAM26360
      GO TO (2201,2202),IGO                                             EAM26370
C                                                                       EAM26380
 2202 CALL MARK(1,8,2,2,5)                                              EAM26390
      RETURN                                                            EAM26400
C                                                                       EAM26410
 5    CALL MARK(1,8,3,2,6)                                              EAM26420
      RETURN                                                            EAM26430
C                                                                       EAM26440
 2201 CALL ACTCAL(2)                                                    EAM26450
      CALL ACTCAL(3)                                                    EAM26460
 6    RETURN                                                            EAM26470
C                                                                       EAM26480
C     EXPERIMENTALLY DETERMINE AR                                       EAM26490
 4    IGO=MODVQ(6)                                                      EAM26500
      GO TO (2301,2302),IGO                                             EAM26510
C                                                                       EAM26520
 2302 CALL MARK(1,9,2,2,7)                                              EAM26530
      RETURN                                                            EAM26540
C                                                                       EAM26550
 7    CALL MARK(1,9,3,2,6)                                              EAM26560
      RETURN                                                            EAM26570
 2301 CALL MIRCAL(2)                                                    EAM26580
      CALL MIRCAL(3)                                                    EAM26590
      RETURN                                                            EAM26600
C                                                                       EAM26610
      END                                                               EAM26620
      SUBROUTINE MIRCAL(NENTRY)
C
C     SUBROUTINE TO CALIBRATE MIRROR
C
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),
     2 GAINM(1600),ASV(3)
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,
     1 DUMVA,GAINV,GAINM,ASV
C
      DIMENSION LACTV(20)
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS
C
      DIMENSION AM(400),AIM(400)
      COMMON/BLKMFC/AM,AIM
C
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),
     3 MODV(20)
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,
     2 NMCXV,NMCPV,NMICPV,MODV
C
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END
C
C     SIGMA 2 DIMENSION STATEMENTS START
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),
     2 QASV(3)
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ
C     SIGMA 2 DIMENSION STATEMENTS END
C
 1000 FORMAT(7H MIRCAL)
 1001 FORMAT(/,13X,2HAM)
C
      GO TO (1,2,3,4,5,6),NENTRY
C
C     INPUT DATA
 1    PRINT 1000
      CALL IRANDP(1,NMEASF,IA,IA,IA,IA,IA,IA,4)
      CALL RANDPD(1,DACT,DA,DA,DA,DA,DA,DA,4)
      DB=2.0*DACT*NMEASF
      DB=1.0/DB
      RETURN
C
C     INITIALIZATION
 2    IGOA=MODV(12)
      RETURN
C
C     MIRROR CALIBRATION
 3    SGAIN=GAINV(1)
      IGOA=MODVQ(6)
      GAINV(1)=0.0
      NTIMS=NFSENS
      NTIMSQ=NTIMS
C     SET AM=0.0
      IA=N*NR
      DO 2100 I=1,IA
 2100 AM(I)=0.0
      I=0
 2101 I=I+1
      J=0
      IF(I-NR)2103,2103,2200
 2103 J=J+1
      IF(J-NMEASF)2104,2104,2208
C     RETURN TO SIGMA 2 TO INITIALIZE EAMCS
 2104 GO TO (2105,2106),IGOA
C*****EAM SOFTWARE TEST CODING******************************************
 2105 CALL EAMCS(8)
      GO TO 4
C*****EAM SOFTWARE TEST CODING******************************************
 2106 CALL MARK(1,22,8,9,4)
      RETURN
C
 4    UFV(I)=-DACT
      QUFV(I)=UFV(I)*ASCALV(I)
      GO TO (2107,2108),IGOA
 2108 CALL MARK(1,22,3,9,5)
      RETURN
C     RETURN TO SIGMA 2 TO ADJUST ACTUATORS AND MEASURE FIGURE ERROR
C
C*****EAM SOFTWARE TEST CODING******************************************
 2107 CALL EAMCS(3)
C*****EAM SOFTWARE TEST CODING******************************************
C
 5    DO 2202 K=1,N
 2202 DUMV(K)=XFV(K)
      UFV(I)=DACT
      QUFV(I)=UFV(I)*ASCALV(I)
      GO TO (2204,2205),IGOA
 2205 CALL MARK(1,22,3,9,6)
      RETURN
C     RETURN TO SIGMA 2 TO ADJUST ACTUATORS AND MEASURE FIGURE ERROR
C
C*****EAM SOFTWARE TEST CODING******************************************
 2204 CALL EAMCS(3)
C*****EAM SOFTWARE TEST CODING******************************************
C
 6    DO 2203 K=1,N
      DUMV(K)=(XFV(K)-DUMV(K))
 2203 AM(K+(I-1)*N)=DUMV(K)+AM(K+(I-1)*N)
 2201 GO TO 2103
 2208 DO 2207 K=1,N
 2207 AM(K+(I-1)*N)=AM(K+(I-1)*N)*DB
      UFV(I)=0.0
      QUFV(I)=0.0
      GO TO 2101
C
C     PRINT OUT MIRROR DEFORMATION-ACTUATOR COMMAND ARRAY
 2200 PRINT 1001
      CALL MXRNP(AM,N,NR,3)
      GAINV(1)=SGAIN
      RETURN
C
      END
      SUBROUTINE MIRMDL(NENTRY,IACT)                                    EAM27860
C                                                                       EAM27870
C     STRUCTURAL MODEL OF THE MIRROR FOR TESTING THE EAM SOFTWARE       EAM27880
C     PACKAGE                                                           EAM27890
C                                                                       EAM27900
C     SIGMA 5 TYPE A DIMENSION STATEMENTS START                         EAM27910
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),         EAM27920
     1 YFSV(20),XFRV(20),DOMV(20),UFAV(20),DUMVA(20),GAINV(10),         EAM27930
     2 GAINM(1600),ASV(3)                                               EAM27940
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DOMV,UFAV,     EAM27950
     1 DUMVA,GAINV,GAINM,ASV                                            EAM27960
C                                                                       EAM27970
      DIMENSION LACTV(20)                                               EAM27980
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM27990
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM28000
C                                                                       EAM28010
      DIMENSION AM(400),AIM(400)                                        EAM28020
      COMMON/BLKMFC/AM,AIM                                              EAM28030
C                                                                       EAM28040
      COMMON/BLKT/T,DT,DTH,DTPLOT,DTNOIS,TPHI,TPRNT,TEND                 EAM28050
C                                                                       EAM28060
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                EAM28070
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),            EAM28080
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),      EAM28090
     3 MODV(20)                                                         EAM28100
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM28110
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM28120
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM28130
C                                                                       EAM28140
      DIMENSION XV(50),NAMV(50),DUMV(20),DUMM(400),PARV(50),IPARV(50),  EAM28150
     1 SXV(50),SPARV(50),ISPARV(50),IDUMV(20)                           EAM28160
      COMMON/BLKSIM/XV,NAMV,DUMV,DUMM,PARV,IPARV,SXV,SPARV,ISPARV,      EAM28170
     1 IDUMV                                                            EAM28180
C                                                                       EAM28190
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)             EAM28200
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM28210
C     SIGMA 5 TYPE A DIMENSION STATEMENTS END                           EAM28220
C                                                                       EAM28230
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM28240
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM28250
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM28260
     2 QASV(3)                                                          EAM28270
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM28280
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM28290
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM28300
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM28310
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM28320
C                                                                       EAM28330
      DIMENSION UV(20)                                                  EAM28340
C                                                                       EAM28350
 1001 FORMAT(/,5X,10HAMM*ASCALE)                                        EAM28360
C                                                                       EAM28370
      GO TO(1,2,3),NENTRY                                               EAM28380
C                                                                       EAM28390
C     INPUT DATA                                                        EAM28400
 1    PRINT 1000                                                        EAM28410
C     READ DEFORMATION FORCE MATRIX FOR ACTUAL MIRROR                   EAM28420
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C     READ IN REDUCED MATRIX IF MODV(10)=2                              EAM28430
      IGO=MODV(10)                                                      EAM28440
      GO TO(2006,2007),IGO                                              EAM28450
 2006 NA=N                                                              EAM28460
      GO TO 2008                                                        EAM28470
 2007 NA=NR                                                             EAM28480
 2008 CALL MXRNP(AMM,N,NA,4)                                            EAM28490
C     SCALE AMM                                                         EAM28500
      IF(GAINV(7)-1.0)2003,2004,2003                                    EAM28510
 2003 IA=N*NA                                                           EAM28520
      DO 2005 I=1,IA                                                    EAM28530
 2005 AMM(I)=AMM(I)*GAINV(7)                                            EAM28540
      PRINT 1001                                                        EAM28550
      CALL MXRNP(AMM,N,NA,3)                                            EAM28560
 2004 CONTINUE                                                          EAM28570
C     READ INITIAL DISTURBANCE INDUCED FIGURE ERROR                     EAM28580
      CALL MXRNP(XFDV,1,N,4)                                            EAM28590
C                                                                       EAM28600
C     INITIALIZATION                                                    EAM28610
C     SET XFAV=XFDV                                                     EAM28620
 2    CALL MCPY(XFDV,XFAV,1,N,0)                                        EAM28630
      DO 2000 I=1,N                                                     EAM28640
      UFAV(I)=0.0                                                       EAM28650
 2000 UV(I)=0.0                                                         EAM28660
      RETURN                                                            EAM28670
C                                                                       EAM28680
C     STRUCTURE SIMULATION                                              EAM28690
C     FORM COMPLETE DISTURBANCE VECTOR UV                               EAM28700
 3    IGO=MODV(10)                                                      EAM28710
      GO TO(2301,2302),IGO                                              EAM28720
 2301 J=0                                                               EAM28730
      DO 2001 I=1,N                                                     EAM28740
      IF(LACTV(I))2002,2001,2002                                        EAM28750
 2002 J=J+1                                                             EAM28760
      UV(I)=UFAV(J)                                                     EAM28770
C                                                                       EAM28780
 1000 FORMAT(7H MIRMDL)                                                 EAM28790
 2001 CONTINUE                                                          EAM28800
C     DUMBV=AMM*UV                                                      EAM28810
      CALL MPRD(AMM,UV,DUMBV,N,N,0,0,1)                                 EAM28820
      GO TO 2303                                                        EAM28830
C     DUMBV=AMMR*UFAV                                                   EAM28840
 2302 CALL MPRD(AMM,UFAV,DUMBV,N,NA,0,0,1)                              EAM28850
C     XFAV=XFDV+DUMBV                                                   EAM28860
 2303 CALL MMADD(N,1.0,XFDV,1.0,DUMBV,XFAV)                             EAM28870
      RETURN                                                            EAM28880
C                                                                       EAM28890
      END                                                               EAM28900
      SUBROUTINE PINDX(NENTRY,PINDEX,YV)                                EAM28910
C                                                                       EAM28920
C     SUBROUTINE TO CALCULATE PERFORMANCE INDICES FOR THE MIRROR FIGURE EAM28930
C     CONTROL SYSTEM                                                    EAM28940
C                                                                       EAM28950
C                                                                       EAM
C     SIGMA 5 TYPE D DIMENSION STATEMENTS START                         EAM
      DIMENSION LACTV( 20)                                              EAM
      COMMON/BKIEAM/LACTV,NCVEL,N,N-,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM
C     SIGMA 5 TYPE C DIMENSION STATEMENTS END                           EAM
C     SIGMA 5 TYPE D DIMENSION STATEMENTS END                           EAM
      DIMENSION WGTV( 20),YV( 1)                                        EAM28960
C                                                                       EAM28970
 1000 FORMAT( 6H PINDX)                                                 EAM28980
C                                                                       EAM28990
      GO TO( 1,2,3),NENTRY                                              EAM29000
C                                                                       EAM29010
C     INPUT DATA                                                        EAM29020
 1    PRINT 1000                                                        EAM29030
      CALL MXRNP( WGTV,1,N,4)                                           EAM29040
      RETURN                                                            EAM29050
C                                                                       EAM29060
C     INITIALIZATION                                                    EAM29070
 2    PINDEX=0.0                                                        EAM29080
      RETURN                                                            EAM29090
C                                                                       EAM29100
C     EVALUATE PERFORMANCE INDEX                                        EAM29110
 3    PINDEX=0.0                                                        EAM29120
      DO 2000 I=1,N                                                     EAM29130
 2000 PINDEX=PINDEX+YV( I )*YV( I )*WGTV( I )                           EAM29140
      PINDEX=SQRT( PINDEX)                                              EAM29150
      RETURN                                                            EAM29160
C                                                                       EAM29170
      END                                                               EAM29180
      SUBROUTINE PLRT(NENTRY,XV,T,DT,NRUN)                              EAM29190
C                                                                       EAM29200
      DIMENSION XV(1),PMAXV(40),FACV(5),PLOTV(45)                       EAM29210
C                                                                       EAM29220
      DIMENSION IPLOTV(40),IMODV(40),SCALV(40),SCALAV(40),SSCALV(40)    EAM29230
C                                                                       EAM29240
      DIMENSION X(200),Y(2000)                                          EAM29250
C                                                                       EAM29260
 1000 FORMAT(5H PLRT)                                                   EAM29270
 1001 FORMAT(10X,5HSCALV)                                               EAM29280
 1003 FORMAT(11X,4HNRUN,9X,6HNPLOTV,11X,4HNPTS,9X,6HDTPLOT,11X,4HTEND)  EAM29290
 1004 FORMAT(9X,6HIPLOTV)                                               EAM29300
 1006 FORMAT(10X,5HPMAXV)                                               EAM29310
 1008 FORMAT(3I15,2F15.6)                                               EAM29320
 1009 FORMAT(6X,9HRUN SCALE)                                            EAM29330
 1012 FORMAT(14H REDIMENSION Y)                                         EAM29340
 1013 FORMAT(14H REDIMENSION X)                                         EAM29350
C                                                                       EAM29360
      GO TO(1,2,3,4,5,6,7,8,9,10,11,12),NENTRY                          EAM29370
C                                                                       EAM29380
C     READ PLOT DATA                                                    EAM29390
 1    PRINT 1000                                                        EAM29400
      CALL IRANDP(1,NPLOTV,IA,IA,IA,IA,IA,IA,4)                         EAM29410
      CALL RANDPD(1,DTPLOT,DA,DA,DA,DA,DA,DA,4)                         EAM29420
      CALL IMXRNP(IPLOTV,1,NPLOTV,4)                                    EAM29430
      CALL IMXRNP(IMODV,1,NPLOTV,4)                                     EAM29440
      CALL MXRNP(SCALV,1,NPLOTV,4)                                      EAM29450
C     READ IN DATA FOR SYSTEM 360 PLOT ROUTINE                          EAM29460
      TEND=T                                                            EAM29470
      CALL STORED(1,RANG,WIDTH,SPAC,SCALAV,X,Y,TEND,NPLOTV,NPTS,NRUN)   EAM29480
      DO 2000 I=1,NPLOTV                                                EAM29490
      SCALAV(I)=SCALV(I)                                                EAM29500
 2000 SSCALV(I)=SCALV(I)                                                EAM29510
      NDIMX=200                                                         EAM29520
      NDIMY=2000                                                        EAM29530
      FACV(1)=1.0                                                       EAM29540
      FACV(2)=1.25                                                      EAM29550
      FACV(3)=2.5                                                       EAM29560
      FACV(4)=5.0                                                       EAM29570
      FACV(5)=7.5                                                       EAM29580
      RETURN                                                            EAM29590
C                                                                       EAM29600
C     INITIALIZE PLOT                                                   EAM29610
 2    TEND=T                                                            EAM29620
      DTH=DT/2.0                                                        EAM29630
      STP=0.0                                                           EAM29640
C                                                                       EAM29650
C     START OF PLOT RUN                                                 EAM29660
C     SET Y AND X TO ZERO                                               EAM29670
 3    DO 2004 I=1,NDIMX                                                 EAM29680
 2004 X(I)=0.0                                                          EAM29690
      DO 2005 I=1,NDIMY                                                 EAM29700
 2005 Y(I)=0.0                                                          EAM29710
C     RESET SCALV TO ORIGINAL VALUE                                     EAM29720
      DO 2002 I=1,NPLOTV                                                EAM29730
      SCALAV(I)=SSCALV(I)                                               EAM29740
 2002 SCALV(I)=RANG/SSCALV(I)                                           EAM29750
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C     DEFINE AND PROTECT THE DATA SET                                   EAM29760
      DA=TEND+0.01*DTPLOT                                               EAM29770
      IA=DA/DTPLOT                                                      EAM29780
      NPTS=IA+1                                                         EAM29790
      NSTORE=0                                                          EAM29800
      IF(NPTS-NDIMX)2120,2120,2130                                      EAM29810
 2130 PRINT 1013                                                        EAM29820
      NPTS=NDIMX                                                        EAM29830
      DA=NPTS-1                                                         EAM29840
      DTPLOT=TEND/DA                                                    EAM29850
 2120 IA=NPTS*NPLOTV                                                    EAM29860
      IF(IA-NDIMY)2100,2100,2110                                        EAM29870
 2110 PRINT 1012                                                        EAM29880
      NPTS=NDIMY/NPLOTV                                                 EAM29890
      DA=NPTS-1                                                         EAM29900
      DTPLOT=TEND/DA                                                    EAM29910
C     INITIALIZE 360 PLOTTING ROUTINE                                   EAM29920
 2100 CALL STORED(2,RANG,WIDTH,SPAC,SCALAV,X,Y,TEND,NPLOTV,NPTS,NRUN)   EAM29930
      RETURN                                                            EAM29940
C                                                                       EAM29950
C     STORE PLOT DATA IN ARRAYS X AND Y EVERY DTPLOT SECONDS            EAM29960
 4    IF(T+DTH-STP)2810,2820,2820                                       EAM29970
 2820 STP=STP+DTPLOT                                                    EAM29980
      NSTORE=NSTORE+1                                                   EAM29990
      X(NSTORE)=T                                                       EAM30000
      K=NSTORE                                                          EAM30010
      DO 2800 I=1,NPLOTV                                                EAM30020
      J=IPLOTV(I)                                                       EAM30030
      Y(K)=XV(J)                                                        EAM30040
 2800 K=K+NPTS                                                          EAM30050
 2810 RETURN                                                            EAM30060
C                                                                       EAM30070
 5    RETURN                                                            EAM30080
 6    RETURN                                                            EAM30090
 7    RETURN                                                            EAM30100
 8    RETURN                                                            EAM30110
C                                                                       EAM30120
C     PLOT DATA FOR ONE RUN                                             EAM30130
C     GENERATE SELECTED SCALE FACTORS                                   EAM30140
 9    DO 2600 I=1,NPLOTV                                                EAM30150
 2600 PMAXV(I)=0.0                                                      EAM30160
C     FIND MAXIMUM MAGNITUDES OF STORED VARIABLES                       EAM30170
      L=1                                                               EAM30180
      M=NPTS                                                            EAM30190
      DO 2610 I=1,NPLOTV                                                EAM30200
      DO 2612 K=L,M                                                     EAM30210
      DA=ABS(Y(K))                                                      EAM30220
      IF(DA-PMAXV(I))2612,2612,2613                                     EAM30230
 2613 PMAXV(I)=DA                                                       EAM30240
 2612 CONTINUE                                                          EAM30250
      L=L+NPTS                                                          EAM30260
 2610 M=M+NPTS                                                          EAM30270
C     GENERATE SCALE FACTORS AUTOMATICALLY                              EAM30280
      DO 2621 K=1,NPLOTV                                                EAM30290
      IGO=IMODV(K)                                                      EAM30300
      GO TO(2621,2615),IGO                                              EAM30310
 2615 DO 2618 I=1,20                                                    EAM30320
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      J=I-10                                                             EAM30330
      DB=10.0**J                                                         EAM30340
      DO 2617 L=1,5                                                      EAM30350
      DA=DB*FACV(L)                                                      EAM30360
      IF(PMAXV(K)-DA)2619,2617,2617                                      EAM30370
 2617 CONTINUE                                                           EAM30380
 2618 CONTINUE                                                           EAM30390
 2619 SCALAV(K)=DA                                                       EAM30400
      SCALV(K)=RANG/DA                                                   EAM30410
 2621 CONTINUE                                                           EAM30420
C     PRINT PLOTTED DATA CHARACTERISTICS                                 EAM30430
      PRINT 1003                                                         EAM30440
      PRINT 1008,NRUN,NPLOTV,NPTS,DTPLOT,TEND                            EAM30450
      PRINT 1004                                                         EAM30460
      CALL IMXRNP(IPLOTV,1,NPLOTV,3)                                     EAM30470
      PRINT 1001                                                         EAM30480
      CALL MXRNP(SCALAV,1,NPLOTV,3)                                      EAM30490
      PRINT 1006                                                         EAM30500
      CALL MXRNP(PMAXV,1,NPLOTV,3)                                       EAM30510
C     SCALE AND LIMIT DATA FOR PLOTTING                                  EAM30520
      L=1                                                                EAM30530
      M=NPTS                                                             EAM30540
      DO 2410 I=1,NPLOTV                                                 EAM30550
      DB=SCALV(I)                                                        EAM30560
      DO 2412 K=L,M                                                      EAM30570
      Y(K)=Y(K)*DB                                                       EAM30580
 2412 CALL SATLIM(Y(K),RANG,IA)                                          EAM30590
      L=L+NPTS                                                           EAM30600
 2410 M=M+NPTS                                                           EAM30610
C     PLOT DATA FOR ONE RUN USING THE 360 PLOTTING ROUTINE               EAM30620
      CALL STORED(3,RANG,WIDTH,SPAC,SCALAV,X,Y,TEND,NPLOTV,NPTS,NRUN)    EAM30630
      RETURN                                                             EAM30640
C                                                                        EAM30650
 10   RETURN                                                             EAM30660
 11   RETURN                                                             EAM30670
C                                                                        EAM30680
C     TERMINATE 360 PLOTTING ROUTINE                                     EAM30690
 12   CALL STORED(4,RANG,WIDTH,SPAC,SCALAV,X,Y,TEND,NPLOTV,NPTS,NRUN)    EAM30700
      RETURN                                                             EAM30710
C                                                                        EAM30720
      END                                                                EAM30730
      SUBROUTINE RESPON(NENTRY)                                         EAM30740
C                                                                       EAM30750
C     SUBROUTINE TO GENERATE THE TIME DOMAIN RESPONSE OF THE            EAM30760
C     EXPERIMENTAL ACTIVE MIRROR                                        EAM30770
C                                                                       EAM30780
C     SIGMA 5 TYPE A DIMENSION STATEMENTS START                         EAM30790
      DIMENSION XFV( 20),UFV( 20),ASCALV( 20),FSCALV( 20),XFSV( 20),    EAM30800
     1 YFSV( 20),XFRV( 20),DOMV( 20),UFAV( 20),DUMVA( 20),GAINV( 10),   EAM30810
     2 GAINM( 1600),ASV( 3)                                             EAM30820
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DOMV,UFAV,     EAM30830
     1 DUMVA,GAINV,GAINM,ASV                                            EAM30840
C                                                                       EAM30850
      DIMENSION LACTV( 20)                                              EAM30860
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,       EAM30870
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS      EAM30880
C                                                                       EAM30890
      DIMENSION AM( 400),AIM( 400)                                      EAM30900
      COMMON/BLKMFC/AM,AIM                                              EAM30910
C                                                                       EAM30920
      COMMON/BLKT/T,DT,DTH,DTPLOT,DTNOIS,TPHI,TPRNT,TEND                EAM30930
C                                                                       EAM30940
      DIMENSION IAV( 30),IBV( 30),ICV( 30),IDV( 30),IEV( 30),           EAM30950
     1 JCXV( 10),JCPV( 10),JICPV( 10),CXV( 10),CPV( 10),ICPV( 10),      EAM30960
     2 CXM( 100),CPM( 100),ICPM( 100),NMCXV( 10),NMCPV( 10),NMICPV( 10),EAM30970
     3 MODV( 20)                                                        EAM30980
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,  EAM30990
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,      EAM31000
     2 NMCXV,NMCPV,NMICPV,MODV                                          EAM31010
C                                                                       EAM31020
      DIMENSION XV( 50),NAMV( 50),DUMV( 20),DUMM( 400),PARV( 50),IPARV( 50),EAM31030
     1 SXV( 50),SPARV( 50),ISPARV( 50),IDUMV( 20)                       EAM31040
      COMMON/BLKSIM/XV,NAMV,DUMV,DUMM,PARV,IPARV,SXV,SPARV,ISPARV,      EAM31050
     1 IDUMV                                                            EAM31060
C                                                                       EAM31070
      DIMENSION AMM( 400),WV( 20),DUMBV( 20),XFAV( 20),XFDV( 20)        EAM31080
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV                              EAM31090
C     SIGMA 5 TYPE A DIMENSION STATEMENTS END                           EAM31100
C                                                                       EAM31110
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM31120
      DIMENSION QXFSV( 20),QYFSV( 20),QDUMVA( 20),QDUMVB( 20),QDUMVC( 20),EAM31130
     1 QUFV( 20),QUFAV( 20),MSEQVQ( 20),MODVQ( 20),IDUMVQ( 10),QUFERV( 20),EAM31140
     2 QASV( 3)                                                         EAM31150
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM31160
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM31170
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM31180
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM31190
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM31200
C                                                                       EAM31210
 1000 FORMAT(/,13X,2HT=,F15.6,8X,7HPINDEX=,F15.6)                       EAM31220
 1001 FORMAT(7H RESPON)                                                 EAM31230
 1002 FORMAT(12X,3HXFV)                                                 EAM31240
 1003 FORMAT(12X,3HUFV)                                                 EAM31250
 1004 FORMAT(11X,4HUFAV)                                                EAM31260
 1005 FORMAT(7F15.6)                                                    EAM31270
 1006 FORMAT(11X,4HXFMN,10X,5HXFSIG,10X,5HAMBIG,9X,6HXFMEAS,            EAM31280
     1 11X,4HXFSW,9X,6HXFLAST,10X,5HLSENS)                              EAM31290
 1007 FORMAT(10X,5HJMEAS,10X,5HJWAIT,10X,5HJSENS,10X,5HISENS,10X,       EAM31300
     1 5HXFACT,9X,6HPINDEX,10X,5HFSOUT)                                 EAM31310
 1008 FORMAT(10X,5HFSERR,7X,8HFSPINDEX,5X,10HFSNOIS SIG,9X,6HFSNOIS,     EAM31320
     1 8X,7HRPINDEX)                                                    EAM31330
 1009 FORMAT(11X,4HXFAV)                                                EAM31340
C                                                                       EAM31350
      GO TO (1,2,3,4,5,6),NENTRY                                        EAM31360
C                                                                       EAM31370
C     INPUT DATA                                                        EAM31380
 1    PRINT 1001                                                        EAM31390
      CALL RANDPD(4,DT,TPRNT,TEND,DTNOIS,DA,DA,DA,4)                    EAM31400
      CALL IRANDP(1,NSSRUN,IA,IA,IA,IA,IA,IA,4)                         EAM31410
      RETURN                                                            EAM31420
C                                                                       EAM31430
C     INITIALIZE SYSTEMS                                                EAM31440
 2    T=0.0                                                             EAM31450
      ST=0.0                                                            EAM31460
      STN=0.0                                                           EAM31470
      STP=0.0                                                           EAM31480
      NTIMSQ=1                                                          EAM31490
C     INITIALIZE THE MIRROR FIGURE CONTROL SYSTEM                       EAM31500
      CALL FSMDL(2,I)                                                   EAM31510
      CALL MIRMDL(2,I)                                                  EAM31520
C*****STATEMENT TO RESET VALUE OF GAINV(1)=PARV(1)**********************EAM31530
      GAINV(1)=PARV(1)                                                  EAM31540
C*****STATEMENT TO RESET VALUE OF GAINV(1)=PARV(1)**********************EAM31550
      CALL MAINA(2)                                                     EAM31560
      CALL MAINA(4)                                                     EAM31570
C     RETURN TO SIGMA 2 TO INITIALIZE EAMCS                             EAM31580
C                                                                       EAM31590
      IGO=MODV(11)                                                      EAM31600
C     TEST REMOTE TERMINAL CONTROL VIA TYPCON IF MODV(11)=2             EAM31610
      IA=8                                                              EAM31620
      GO TO(2201,2202),IGO                                              EAM31630
 2202 IA=2                                                              EAM31640
 2201 CONTINUE                                                          EAM31650
C                                                                       EAM31660
      IGO=MODV(12)                                                      EAM31670
      GO TO (2002,2000),IGO                                             EAM31680
 2000 CALL MARK(1,22,IA,7,4)                                            EAM31690
      RETURN                                                            EAM31700
C                                                                       EAM31710
C*****EAM SOFTWARE TEST CODING******************************************EAM31720
 2002 CALL EAMCS(IA)                                                    EAM31730
C*****EAM SOFTWARE TEST CODING******************************************EAM31740
 4    CALL PLRT(2,XV,TEND,DT,NRUN)                                      EAM31750
      RETURN                                                            EAM31760
C                                                                       EAM31770
C     PERFORM SIMULATION                                                EAM31780
 3    CONTINUE                                                          EAM31790
C     CHECK TO SEE IF SENSE SWITCH NSSRUN IS RESET IF MODV(1)=1         EAM31800
      IGO=MODV(1)                                                       EAM31810
      GO TO(2011,2007),IGO                                              EAM31820
 2011 CALL TYPOUT(NSSRUN,1)                                             EAM31830
 2010 CONTINUE                                                          EAM31840
      IF(SNSWT(NSSRUN))2010,2020,2020                                   EAM31850
 2020 CONTINUE                                                          EAM31860
C                                                                       EAM31870
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C     START RUN BY SETTING SENSE SWITCH NSSRUN IF MODV(1)=1             EAM31880
 2012 CALL TYPOUT(NSSRUN,1)                                             EAM31890
 2004 CONTINUE                                                          EAM31900
      IF(SNSWT(NSSRUN))2007,2004,2004                                   EAM31910
C                                                                       EAM31920
C     STOCHASTIC STRUCTURAL DISTURBANCE GENERATOR                       EAM31930
 2005 IF(T+DTH-STN)2052,2053,2053                                       EAM31940
 2053 STN=STN+DTNOIS                                                    EAM31950
      CALL NOIS(3)                                                      EAM31960
C                                                                       EAM31970
C     OUTPUT PRINTED DATA                                               EAM31980
 2052 IF(T+DTH-ST)2008,2006,2006                                        EAM31990
 2006 CONTINUE                                                          EAM32000
C     OUTPUT PRINT                                                      EAM32010
      PRINT 1000,T,DOMV(13)                                             EAM32020
      IGO=MODV(8)                                                       EAM32030
      GO TO(2100,2101),IGO                                              EAM32040
 2100 PRINT 1009                                                        EAM32050
      CALL MXRNP(XFAV,1,N,3)                                            EAM32060
 2101 PRINT 1002                                                        EAM32070
      CALL MXRNP(XFV,1,N,3)                                             EAM32080
      PRINT 1003                                                        EAM32090
      CALL MXRNP(UFV,1,NR,3)                                            EAM32100
      PRINT 1004                                                        EAM32110
      CALL MXRNP(UFAV,1,NR,3)                                           EAM32120
      PRINT 1006                                                        EAM32130
      CALL MXRNP(DOMV,1,7,3)                                            EAM32140
      PRINT 1007                                                        EAM32150
      PRINT 1005,(DOMV(I),I=8,14)                                       EAM32160
      PRINT 1008                                                        EAM32170
      PRINT 1005,(DOMV(I),I=15,19)                                      EAM32180
C     OUTPUT PRINT                                                      EAM32190
      ST=ST+TPRNT                                                       EAM32200
 2008 CONTINUE                                                          EAM32210
C                                                                       EAM32220
C     AUXILLIARY PLOTTED DATA                                           EAM32230
C     AUXILLIARY PLOTTED DATA                                           EAM32240
C                                                                       EAM32250
C     OUTPUT PLOTTED DATA                                               EAM32260
C     STORE DATA IF MODV(2)=2                                           EAM32270
      IGO=MODV(2)                                                       EAM32280
      GO TO(2103,2102),IGO                                              EAM32290
 2102 CALL PLRT(4,XV,T,DT,NRUN)                                         EAM32300
      GO TO 2104                                                        EAM32310
C     PLOT DATA ONLINE IF MODV(2)=1                                     EAM32320
 2103 CALL PLRT(8,XV,T,DT,NRUN)                                         EAM32330
C                                                                       EAM32340
C     INCREMENT COMPUTER TIME                                           EAM32350
 2104 T=T+DT                                                            EAM32360
C                                                                       EAM32370
C     T=TEND                                                            EAM32380
      IF(T+DTH-TEND)2007,2001,2001                                      EAM32390
C                                                                       EAM32400
C     EXPERIMENTAL ACTIVE MIRROR SIMULATION COMPUTATIONS                EAM32410
 2007 IGO=MODV(12)                                                      EAM32420
      GO TO (2106,2105),IGO                                             EAM32430
C*****EAM SOFTWARE TEST CODING*******************************************EAM32440
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 2106 CALL EAMCS(4)                                                         EAM32450
      GO TO 5                                                               EAM32460
C*****EAM SOFTWARE TEST CODING******************************************EAM32470
 2105 CALL MARK(1,22,4,7,5)                                                 EAM32480
      RETURN                                                                EAM32490
C                                                                           EAM32500
 5    CONTINUE                                                              EAM32510
C                                                                           EAM32520
C     SIMULATION CYCLE TERMINATION                                          EAM32530
C     TERMINATE RUN IF SENSE SWITCH NSSRUN IS RESET                         EAM32540
C     AND MODV(1)=1                                                         EAM32550
 2121 IGO=MODV(1)                                                           EAM32560
      GO TO(2122,2005),IGO                                                  EAM32570
 2122 IF(SNSWT(NSSRUN))2005,2001,2001                                       EAM32580
 2001 RETURN                                                                EAM32590
C                                                                           EAM32600
C     OPERATE THE FIGURE CONTROL SYSTEM                                     EAM32610
 6    RETURN                                                                EAM32620
C                                                                           EAM32630
      END                                                                   EAM32640
```

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      SUBROUTINE SIMSYS(NENTRY)                                             EAM32650
C                                                                           EAM32660
C     MAIN CONTROL PROGRAM FOR SIMULATION                                   EAM32670
C.                                                                          EAM32680
C     SIGMA 5 TYPE A DIMENSION STATEMENTS START                             EAM32690
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),             EAM32700
     1 YFSV(20),XFRV(20),DOMV(20),UFAV(20),DUMVA(20),GAINV(10),             EAM32710
     2 GAINM(1600),ASV(3)                                                   EAM32720
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DOMV,UFAV,         EAM32730
     1 DUMVA,GAINV,GAINM,ASV                                                EAM32740
C                                                                           EAM32750
C                                                                           EAM32760
      DIMENSION LACTV(20)                                                   EAM32770
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,           EAM32780
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS          EAM32790
C                                                                           EAM32800
      DIMENSION AM(400),AIM(400)                                            EAM32810
      COMMON/BLKMFC/AM,AIM                                                  EAM32820
C                                                                           EAM32830
      COMMON/BLKT/T,DT,DTH,DTPLOT,DTNOIS,TPHI,TPRNT,TEND                    EAM32840
C                                                                           EAM32850
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),                    EAM32860
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),                EAM32870
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),          EAM32880
     3 MODV(20)                                                             EAM32890
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,      EAM32900
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,          EAM32910
     2 NMCXV,NMCPV,NMICPV,MODV                                              EAM32920
C                                                                           EAM32930
      DIMENSION XV(50),NAMV(50),DUMV(20),DUMM(400),PARV(50),IPARV(50),      EAM32940
     1 SXV(50),SPARV(50),ISPARV(50),IDUMV(20)                               EAM32950
      COMMON/BLKSIM/XV,NAMV,DUMV,DUMM,PARV,IPARV,SXV,SPARV,ISPARV,          EAM32960
     1 IDUMV                                                                EAM32970
C                                                                           EAM32980
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)                 EAM32990
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV
C     SIGMA 5 TYPE A DIMENSION STATEMENTS END
C


C     SIGMA 2 DIMENSION STATEMENTS START
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),
     2 QASV(3)
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMFASQ,NFSENQ,NTIMSQ,LSENS,
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ
C     SIGMA 2 DIMENSION STATEMENTS END
C
 1000 FORMAT(7H SIMSYS)
 1001 FORMAT(3X,1H*,9A4,4X,9A4)
 1002 FORMAT(3X,1H ,9A4,3X,1H*,9A4)
 1003 FORMAT(/,23H SIMULATION TIMING DATA)
 1004 FORMAT(/,42H RUN SET IDENTIFICATION AND NUMBER OF RUNS,/)
 1005 FORMAT(/,14H PLOTTING DATA)
 1006 FORMAT(/,28H DATA MODIFICATIONS FOR RUNS,/)
 1010 FORMAT(/,1X,7HNEW RUN,7X,5HNRUN=,I10,4X,6HNRUNC=,I5,/)
 1011 FORMAT(1H1)
 1020 FORMAT(18A4)
 1021 FORMAT(/,1X,16HOPERATING MODES*,/)
 1022 FORMAT(/)
 1023 FORMAT(62H THE MARSHALL SPACE FLIGHT CENTER MIRROR FIGURE CONTROL
     1SYSTEM,/,53H DEVELOPED BY THE MIT CHARLES STARK DRAPER LABORATORY,
     2 /)
C
      GO TO (1,2,3,4,5,6),NENTRY
C
C     READ AND PRINT PROGRAM HEADING CONSISTING OF N CARDS IN A
C     FORMAT
    1 CALL IRANDP(1,N,IA,IA,IA,IA,IA,IA,4)
      DO 2008 I=1,N
      READ 1020,(NAMV(J),J=1,18)
      PRINT 1020,(NAMV(J),J=1,18)
 2008 CONTINUE
      PRINT 1011
      PRINT 1023
      PRINT 1000
C
C     READ IN BASIC SIMULATION DATA
C     READ MODV AND IDENTIFY OPERATING MODES
      NMODV=12
      CALL IMXRNP(MODV,1,NMODV,4)
      PRINT 1021
      DO 2005 I=1,NMODV
      READ 1020,(NAMV(J),J=1,18)
      IGO=MODV(I)
      GO TO(2006,2007),IGO
 2006 PRINT 1001,(NAMV(J),J=1,9),(NAMV(J),J=10,18)
      GO TO 2005
 2007 PRINT 1002,(NAMV(J),J=1,9),(NAMV(J),J=10,18)
 2005 CONTINUE
      PRINT 1022
C
C     TRANSFER MODV DATA TO THE SIGMA 2
      DO 2010 I=1,NMODV
 2010 MODVQ(I)=MODV(I)
```

```
C
      PRINT 1003
C     READ IN RESPON DATA
      CALL RESPON( 1)
      DTH=DT/2.0
C
C     READ IN STARTING RUN NUMBER AND TOTAL NUMBER OF RUNS TO BE MADE
      PRINT 1011
      PRINT 1004
      CALL IRANDP( 2,NRUN,NRUNM,IA,IA,IA,IA,IA,4)
C
      NRUNC=0
      NXV=50
      NPV=50
      NIPV=50
C     SET SIMULATION VALUES TO ZERO INITIALLY
      DO 2100 I=1,NXV
 2100 XV( I)=0.0
      DO 2101 I=1,NPV
 2101 PARV( I)=0.0
      DO 2102 I=1,NIPV
 2102 IPARV( I)=0
C
C     READ IN NAMES AND NUMBERS OF EDITED ELEMENTS
      PRINT 1000
      PRINT 1006
      CALL IRANDP( 3,NCXV,NCPV,NICPV,IA,IA,IA,IA,4)
      CALL NPDRNP( DUMV,JCXV,NMCXV,1,NCXV,4)
      CALL NPDRNP( DUMV,JCPV,NMCPV,1,NCPV,4)
      CALL NPDRNP( DUMV,JICPV,NMICPV,1,NICPV,4)
C
      IGO=MODV( 1)
      GO TO( 2003,2002),IGO
C
C     AUTOMATIC MODE
C     READ STORED VALUES OF PARV AND IPARV
 2002 CALL MXRNP( CXM,NRUNM,NCXV,4)
      CALL MXRNP( CPM,NRUNM,NCPV,4)
      CALL IMXRNP( ICPM,NRUNM,NICPV,4)
C
C     READ DATA IN SUBROUTINES
      PRINT 1011
 2003 CALL TYPOUT( IA,4)
      PRINT 1005
      CALL PLRT( 1,XV,T,DT,NRUN)
C
C     INITIALIZE DATA STORAGE FILE
 2004 CALL PLRT( 2,XV,TEND,DT,NRUN)
      NRUNC=0
      IF( NRUN)2110,2110,2120
 2110 NRUN=1
C     ESTABLISH NEW FILE
 2111 CALL PLRT( 3,XV,T,DT,NRUN)
      GO TO 2121
C     FIND START OF RUN IN OLD FILE
 2120 CALL PLRT( 5,XV,T,DT,NRUN)
      GO TO 2111
 2121 CONTINUE
      PRINT 1011
C
C     READ IN DATA FOR THE EXPERIMENTAL ACTIVE MIRROR
      CALL MFCS( 1)
      CALL MAINA( 1)
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C                                                                       EAM34250
C     TRANSFER EAM DATA TO XV,PARV AND IPARV                            EAM34260
C     DEFINE UTILIZED DIMENSIONS OF XV,PARV AND IPARV                   EAM34270
      NXMAX=0                                                           EAM34280
      NPARV=10                                                          EAM34290
      NIPARV=10                                                         EAM34300
C     XV IS NOT USED FOR DATA STORAGE AT THE MOMENT                     EAM34310
C     CONTENTS OF PARV=GAINV                                            EAM34320
C               GAIN         DT      TEND    FSTFLT    PACTTC    FSNSIG EAM34330
C             ASCALE                                                    EAM34340
      GAINV( 2)=DT                                                      EAM34350
      GAINV( 3)=TEND                                                    EAM34360
      DO 2131 I=1,NPARV                                                 EAM34370
 2131 PARV( I)=GAINV( I)                                                EAM34380
C     CONTENTS OF IPARV                                                 EAM34390
C              NSENS     NWAIT       NPOS     NMINT     NMEAS      NTIMS EAM34400
C              MODOP                                                    EAM34410
      IPARV( 1)=NSENS                                                   EAM34420
      IPARV( 2)=NWAIT                                                   EAM34430
      IPARV( 3)=NPOS                                                    EAM34440
      IPARV( 4)=NMINT                                                   EAM34450
      IPARV( 5)=NMEAS                                                   EAM34460
      IPARV( 6)=NTIMS                                                   EAM34470
      IPARV( 7)=MODOP                                                   EAM34480
C                                                                       EAM34490
C     STORE XV,PARV, AND IPARV IN SXV,SPARV, AND ISPARV                 EAM34500
      CALL MCPY( XV,SXV,1,NXMAX,0)                                      EAM34510
      CALL MCPY( PARV,SPARV,1,NPARV,0)                                  EAM34520
      CALL IMCPY( IPARV,ISPARV,1,NIPARV,0)                              EAM34530
C                                                                       EAM34540
C                                                                       EAM34550
C                                                                       EAM34560
C     REINITIALIZE SIMULATION                                           EAM34570
 2    PRINT 1010,NRUN,NRUNC                                             EAM34580
      T=0.0                                                             EAM34590
C                                                                       EAM34600
C     RESET XV,PARV AND IPARV TO ORIGINAL VALUES                        EAM34610
      CALL MCPY( SXV,XV,1,NXMAX,0)                                      EAM34620
      CALL MCPY( SPARV,PARV,1,NPARV,0)                                  EAM34630
      CALL IMCPY( ISPARV,IPARV,1,NIPARV,0)                              EAM34640
      IGO=MODV( 1)                                                      EAM34650
      GO TO( 2401,2402),IGO                                             EAM34660
C                                                                       EAM34670
C     MANUAL MODE                                                       EAM34680
C     READ IN NEW VALUES AND EDIT XV,PARV AND IPARV                     EAM34690
 2401 CALL EDITA( XV,CXV,JCXV,NCXV,2)                                   EAM34700
      CALL EDITA( PARV,CPV,JCPV,NCPV,2)                                 EAM34710
      CALL IEDITA( IPARV,ICPV,JICPV,NICPV,2)                            EAM34720
 2402 IGO=MODV( 1)                                                      EAM34730
      GO TO( 2200,2400),IGO                                             EAM34740
C                                                                       EAM34750
C     AUTOMATIC MODE                                                    EAM34760
C     EXTRACT NEW VALUES FROM MEMORY                                    EAM34770
 2400 IF( NRUNC-NRUNM)2103,2108,2108                                    EAM34780
 2108 RETURN                                                            EAM34790
 2103 IA=NRUNC+1                                                        EAM34800
      DO 2105 I=1,NCXV                                                  EAM34810
 2105 CXV( I)=ELM( CXM,IA,I,NRUNM)                                      EAM34820
      DO 2106 I=1,NCPV                                                  EAM34830
 2106 CPV( I)=ELM( CPM,IA,I,NRUNM)                                      EAM34840
      DO 2107 I=1,NICPV                                                 EAM34850
 2107 ICPV( I)=IELM( ICPM,IA,I,NRUNM)                                   EAM34860
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C                                                                       EAM34870
C     EDIT XV,PARV AND IPARV                                            EAM34880
      CALL EDITA(XV,CXV,JCXV,NCXV,3)                                    EAM34890
      CALL EDITA(PARV,CPV,JCPV,NCPV,3)                                  EAM34900
      CALL IEDITA(IPARV,ICPV,JICPV,NICPV,3)                             EAM34910
C                                                                       EAM34920
C     PRINT MODIFIED VALUES OF XV,PARV AND IPARV FOR CHECK PURPOSES     EAM34930
      CALL NPDRNP(CXV,JCXV,NMCXV,1,NCXV,7)                              EAM34940
      CALL NPDRNP(CPV,JCPV,NMCPV,1,NCPV,7)                              EAM34950
      CALL NPDRNP(DUMV,ICPV,NMICPV,1,NICPV,8)                           EAM34960
C                                                                       EAM34970
 2200 CONTINUE                                                          EAM34980
C                                                                       EAM34990
C     TRANSFER XV,PARV AND IPARV DATA TO THE EXPERIMENTAL ACTIVE MIRROR EAM35000
      DT=PARV(2)                                                        EAM35010
      TEND=PARV(3)                                                      EAM35020
      NSENS=IPARV(1)                                                    EAM35030
      NWAIT=IPARV(2)                                                    EAM35040
      NPOS=IPARV(3)                                                     EAM35050
      NMINT=IPARV(4)                                                    EAM35060
      NMEAS=IPARV(5)                                                    EAM35070
      NTIMS=IPARV(6)                                                    EAM35080
      MODOP=IPARV(7)                                                    EAM35090
      CALL MCPY(PARV,GAINV,1,NPARV,0)                                   EAM35100
C                                                                       EAM35110
C     INITIALIZE THE EXPERIMENTAL ACTIVE MIRROR                         EAM35120
      IGO=MODV(12)                                                      EAM35130
      GO TO (2133,2134),IGO                                             EAM35140
 2134 CALL MARK(1,7,2,1,4)                                              EAM35150
      RETURN                                                            EAM35160
C                                                                       EAM35170
 2133 CALL RESPON(2)                                                    EAM35180
C                                                                       EAM35190
C     SIMULATE EXPERIMENTAL ACTIVE MIRROR                               EAM35200
C                                                                       EAM35210
 4    IGO=MODV(12)                                                      EAM35220
      GO TO (3,2136),IGO                                                EAM35230
 2136 CALL MARK(1,7,3,1,5)                                              EAM35240
      RETURN                                                            EAM35250
C                                                                       EAM35260
 3    CALL RESPON(3)                                                    EAM35270
C                                                                       EAM35280
C     TERMINATE SIMULATION RUN                                          EAM35290
C     IDENTIFY END OF RUN                                               EAM35300
 5    CALL PLRT(9,XV,T,DT,NRUN)                                         EAM35310
C                                                                       EAM35320
C     INCREMENT DATA FILE PARAMETERS                                    EAM35330
      NRUN=NRUN+1                                                       EAM35340
      CALL PLRT(3,XV,T,DT,NRUN)                                         EAM35350
      NRUNC=NRUNC+1                                                     EAM35360
C     TERMINATE 360 PLOTTING ROUTINE                                    EAM35370
      IF(NRUNC-NRUNM)2,2500,2500                                        EAM35380
 2500 CALL PLRT(12,XV,T,DT,NRUN)                                        EAM35390
      GO TO 1                                                           EAM35400
C                                                                       EAM35410
C     EDIT DATA TO CORRESPOND TO NRUNC=NFLGC                            EAM35420
 6    NRUNC=NFLGC-1                                                     EAM35430
      GO TO 2                                                           EAM35440
C                                                                       EAM35450
C                                                                       EAM35460
      END                                                               EAM35470
      SUBROUTINE STORED( NENTRY,RANG,WIDTH,SPAC,SCALV,X,Y,XSPRED,NPLOTV, EAM35480
     1 NPTS,NRUN)                                                       EAM35490
C                                                                       EAM35500
      DIMENSION SCALV( 1),X( 1),Y( 1),TITLE( 2),HEADNG( 10)             EAM35510
C                                                                       EAM35520
      DOUBLE PRECISION PROB,PROG,PAPER,TYPINK                           EAM35530
C                                                                       EAM35540
      DATA PROB,PROG,PAPER,TYPINK /8HM9040    ,8H6362    ,8HWHITE   ,   EAM35550
     1 8HBLACK   /                                                      EAM35560
      DATA TITLE/'NRUN',' =  '/                                         EAM35570
      DATA HEADNG/'EXPE','RIME','NTAL',' ACT','IVE ','MIRR','OR S',     EAM35580
     1 'IMUL','ATIO','N   '/                                            EAM35590
C                                                                       EAM35600
 1000 FORMAT( 7H STORED)                                                EAM35610
C                                                                       EAM35620
      GO TO( 1111,2222,3333,4444),NENTRY                                EAM35630
C                                                                       EAM35640
C     DATA INPUT                                                        EAM35650
 1111 PRINT 1000                                                        EAM35660
      CALL RANDPD( 3,RANG,WIDTH,SPAC,DA,DA,DA,DA,4)                     EAM35670
      CALL NEWPLT( PROB,PROG,PAPER,TYPINK)                              EAM35680
      XBEGIN=0.0                                                        EAM35690
      XEND=0.0                                                          EAM35700
      RETURN                                                            EAM35710
C                                                                       EAM35720
C     INITIALIZATION                                                    EAM35730
 2222 DIST=SPAC+2.0*RANG                                                EAM35740
C     DY = NO. OF INCHES PER ABSCISSA UNIT                              EAM35750
      DY=WIDTH/XSPRED                                                   EAM35760
      SPRED=XSPRED                                                      EAM35770
      RETURN                                                            EAM35780
C                                                                       EAM35790
 3333 CONTINUE                                                          EAM35800
      DO 500 I=1,NPTS                                                   EAM35810
C     CONVERT X VECTOR TO INCHES                                        EAM35820
  500 X( I)=X( I)*DY                                                    EAM35830
C                                                                       EAM35840
C     CREATE NEW REFERENCE POINT                                        EAM35850
      XNEW=XEND+2.0*( SPAC+RANG)                                        EAM35860
      CALL PLOT1( XNEW,0.,-3)                                           EAM35870
C                                                                       EAM35880
C     LABEL EACH SET OF PLOTS                                           EAM35890
      DA=-( 2.0*SPAC)                                                   EAM35900
      DB=0.5*SPAC                                                       EAM35910
      DC=8.0*DB                                                         EAM35920
      CALL SYMBL5( DA,0.0,DB,HEADNG,90.0,40)                            EAM35930
      DA=-SPAC                                                          EAM35940
      CALL SYMBL5( DA,0.0,DB,TITLE,90.0,8)                              EAM35950
      CALL NUMBR1( DA,DC,DB,NRUN,90.0,-1)                               EAM35960
C                                                                       EAM35970
C     PLOT THE NPLOTV GRAPHS                                            EAM35980
      III=0                                                             EAM35990
      DB=0.20*SPAC                                                      EAM36000
      DC=WIDTH+SPAC                                                     EAM36010
      DO 540 J=1,NPLOTV                                                 EAM36020
C                                                                       EAM36030
C     DRAW ABSCISSA                                                     EAM36040
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      CALL PLOT1( XBEGIN,0.0,3)                                         EAM36050
      XEND=XBEGIN+2.0*RANG                                              EAM36060
      CALL PLOT1( XEND,0.0,2)                                           EAM36070
C                                                                       EAM36080
C     DRAW ORDINATE                                                     EAM36090
      XMIDDL=XBEGIN+RANG                                                EAM36100
      CALL PLOT1( XMIDDL,0.0,3)                                         EAM36110
      CALL PLOT1( XMIDDL,WIDTH,2)                                       EAM36120
C                                                                       EAM36130
C     LABEL WITH SCALE VALUE                                            EAM36140
      DA=XBEGIN-0.10*SPAC                                               EAM36150
      CALL NUMBR1( DA,0.0,DB,SCALV( J),90.0,6)                          EAM36160
      CALL NUMBR1( DA,DC,DB,J,90.0,-1)                                  EAM36170
      XBEGIN=XBEGIN+DIST                                                EAM36180
      YYY=RANG+( J-1)*DIST                                              EAM36190
C                                                                       EAM36200
C     PLOT DATA ON COORDINATES                                          EAM36210
      DO 530 I=1,NPTS                                                   EAM36220
      DO 530 I=1,NPTS                                                   EAM36220
      III=III+1                                                         EAM36230
C     NEGATE Y TO ACCOUNT FOR ROTATION OF 90 DEGREES                    EAM36240
C     X=-Y FORMER                                                       EAM36250
C     Y=X FORMER                                                        EAM36260
      Y( III)=-Y( III)+YYY                                              EAM36270
 530  CONTINUE                                                          EAM36280
C     JJJ DENOTES THE BEGINNING OF THE JTH COLUMN VECTOR IN ARRAY Y.    EAM36290
      JJJ=III-NPTS+1                                                    EAM36300
      CALL GRAPH( Y( JJJ),X,NPTS,0.,0.)                                 EAM36310
 540  CONTINUE                                                          EAM36320
C                                                                       EAM36330
C     PRINT THE ABSISSA SCALE                                           EAM36340
      DA=XBEGIN-DIST+2.0*RANG+0.10*SPAC+DB                              EAM36350
      CALL NUMBR1( DA,0.0,DB,0.0,90.0,6)                                EAM36360
      CALL NUMBR1( DA,WIDTH,DB,SPRED,90.0,6)                            EAM36370
      RETURN                                                            EAM36380
C                                                                       EAM36390
 4444 XEND=XEND+10.0                                                    EAM36400
      CALL PLOT1( XEND,0.,-3)                                           EAM36410
      CALL ENDPLT                                                       EAM36420
      RETURN                                                            EAM36430
C                                                                       EAM36440
      END                                                               EAM36450
      SUBROUTINE SUPE2                                                  EAM36460
C                                                                       EAM36470
C     SUPERVISORY PROGRAM FOR THE SIGMA 2 SOFTWARE                      EAM36480
C                                                                       EAM36490
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM36500
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM36510
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM36520
     2 QASV(3)                                                          EAM36530
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM36540
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM36550
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM36560
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM36570
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM36580
C                                                                       EAM36590
      GO TO(1,2,3,4),NFLGA                                              EAM36600
C                                                                       EAM36610
C     CALLS TO ACTCMD                                                   EAM36620
 1    CALL ACTCMD(NFLGB)                                                EAM36630
      GO TO 2000                                                        EAM36640
C                                                                       EAM36650
C     CALLS TO EAMCS                                                    EAM36660
 2    CALL EAMCS(NFLGB)                                                 EAM36670
      GO TO 2000                                                        EAM36680
C     CALLS TO FIGSEN                                                   EAM36690
C                                                                       EAM36700
 3    CALL FIGSEN(NFLGB)                                                EAM36710
      GO TO 2000                                                        EAM36720
C                                                                       EAM36730
C     CALLS TO TYPCON(NFLGB)                                            EAM36740
 4    CALL TYPCON(NFLGB)                                                EAM36750
C                                                                       EAM36760
C     PUT CODING TO TRANSFER CONTROL TO SIGMA 5 HERE                    EAM36770
 2000 RETURN                                                            EAM36780
C                                                                       EAM36790
      END                                                               EAM36800
```

```
C     SUPE5 MAIN SUPERVISORY PROGRAM FOR THE SIGMA 5                    EAM36810
C                                                                       EAM36820
C     SUPERVISORY PROGRAM FOR THE SIGMA 5 SOFTWARE                      EAM36830
C                                                                       EAM36840
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM36850
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM36860
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM36870
     2 QASV(3)                                                          EAM36880
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM36890
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM36900
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM36910
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM36920
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM36930
C                                                                       EAM36940
      COMMON/BLKSUP/ITRANS                                              EAM36950
C                                                                       EAM36960
C     INITIALIZATION                                                    EAM36970
 2010 IF(ISTART-9999)2000,2007,2000                                     EAM36980
C     SET ISTART=9999 THE FIRST TIME SUPE5 IS EXECUTED                  EAM36990
 2000 ISTART=9999                                                       EAM37000
```

```
      CALL MARK(4,IA,IA,IA,IA)
      CALL MARK(1,1,1,19,1)
      ISTORE=0
C
C     OPERATION
 2005 CONTINUE
 2004 IF(ITRANS-ISTORE)2002,2002,2001
 2001 CALL MARK(2,NFLGA,NFLGB,IA,IA)
      GO TO 2003
 2002 CALL MARK(3,IA,IA,NFLGA,NFLGB)
 2003 ISTORE=ITRANS
C
      GO TO(1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,
     1 20,21,21,21,21),NFLGA
C
 1    CALL SIMSYS(NFLGB)
      GO TO 2004
 2    CALL MFCS(NFLGB)
      GO TO 2004
 3    CALL MAINA(NFLGB)
      GO TO 2004
 4    CALL MAINB(NFLGB)
      GO TO 2004
 5    CALL FSMDL(NFLGB,INDEX)
      GO TO 2004
 6    CALL MIRMDL(NFLGB,INDEX)
      GO TO 2004
 7    CALL RESPON(NFLGB)
      GO TO 2004
 8    CALL ACTCAL(NFLGB)
      GO TO 2004
 9    CALL MIRCAL(NFLGB)
      GO TO 2004
 10   CALL ACTMDL(NFLGB,INDEX)
      GO TO 2004
 11   GO TO 2004
 12   GO TO 2004
 13   GO TO 2004
 14   GO TO 2004
 15   GO TO 2004
 16   GO TO 2004
 17   GO TO 2004
 18   GO TO 2004
 19   GO TO 2100
 20   GO TO 2100
C
C     INSERT CODING HERE TO TRANSFER TO THE SIGMA 2 COMPUTER
 21   NFLGA=NFLGA-20
C     SIGMA 5 CONFIGURATION
 2008 CALL SUPE2
C
C     ESTABLISH TRANSFERS ON RETURN TO SIGMA 5
 2007 CONTINUE
      GO TO(2201,2202,2203,2204,2205,2206,2207,2208,2209,2210,
     1 2211,2212,2213,2214,2215,2216,2217,2218,2219,2220,2221),NFLGA
C
 2201 CALL MARK(1,24,2,22,10)
      GO TO 2020
 2202 CALL MARK(1,24,2,22,11)
      GO TO 2020
 2203 CALL MARK(1,21,5,22,12)
      GO TO 2020
 2204 CALL MARK(1,6,3,22,7)
      GO TO 2020
 2205 CALL MARK(1,23,2,22,13)
      GO TO 2020
 2206 GO TO 2020
 2207 CALL MARK(1,10,3,21,4)
      GO TO 2020
 2208 CALL MARK(1,3,6,22,5)
      GO TO 2020
 2209 CALL MARK(1,21,3,22,16)
      GO TO 2020
 2210 CALL MARK(1,5,5,22,17)
      GO TO 2020
 2211 CALL MARK(1,5,3,23,4)
      GO TO 2020
 2212 CALL MARK(1,4,5,24,3)
      GO TO 2020
 2213 CALL MARK(1,4,3,24,8)
      GO TO 2020
 2214 CALL MARK(1,4,4,24,7)
      GO TO 2020
 2215 GO TO 2020
 2216 CALL MARK(1,23,3,22,14)
      GO TO 2020
 2217 CALL MARK(1,3,7,22,18)
      GO TO 2020
 2218 CALL MARK(1,3,5,22,6)
      GO TO 2020
 2219 CALL MARK(1,2,3,24,2)
      GO TO 2020
 2220 CALL MARK(1,2,4,24,2)
      GO TO 2020
 2221 CALL MARK(1,24,2,22,19)
      GO TO 2020
 2222 CALL MARK(1,1,6,24,2)
C
 2020 GO TO 2004
C
C     RESTART PROGRAM
 2100 ISTART=0
      GO TO 2010
C
C     INSERT CODING TO TRANSFER TO THE SIGMA 2 HERE
 2009 CONTINUE
C
      END
      SUBROUTINE TYPCON(NENTRY)                                         EAM38090
C                                                                       EAM38100
C     SIGMA 2 ROUTINE FOR TYPEWRITER CONTROL OF THE EXPERIMENTAL        EAM38110
C     ACTIVE MIRROR                                                     EAM38120
C                                                                       EAM38130
C     SIGMA 2 DIMENSION STATEMENTS START                                EAM38140
      DIMENSION QXFSV(20),QYFSV(20),QDUMVA(20),QDUMVB(20),QDUMVC(20),   EAM38150
     1 QUFV(20),QUFAV(20),MSEQVQ(20),MODVQ(20),IDUMVQ(10),QUFERV(20),   EAM38160
     2 QASV(3)                                                          EAM38170
      COMMON/SIGTWO/QXFSV,QYFSV,QDUMVA,QDUMVB,QDUMVC,QUFV,QUFAV,QXF,    EAM38180
     1 MSEQVQ,NSENSQ,NWAITQ,NPOSQ,NMINTQ,NMEASQ,NFSENQ,NTIMSQ,LSENS,    EAM38190
     2 NFLGA,NFLGB,NFLGC,NFLGD,NFLGE,NTYPOQ,NTYPIQ,MODVQ,NQ,NRQ,        EAM38200
     3 QDT,QDTE,QUFMAX,MODEQ,QGA,QGB,QUFERV,IDUMVQ,QASV,NCVELQ          EAM38210
C     SIGMA 2 DIMENSION STATEMENTS END                                  EAM38220
C                                                                       EAM38230
 1000 FORMAT(1X,A4)                                                     EAM38240
 1001 FORMAT(11H WRONG NAME)                                            EAM38250
 1002 FORMAT(10I3)                                                      EAM38260
 1003 FORMAT(7H NAME=?)                                                 EAM38270
 1004 FORMAT(4H I=?)                                                    EAM38280
 1005 FORMAT(10F12.6)                                                   EAM38290
 1006 FORMAT(7H MODE=?)                                                 EAM38300
 1007 FORMAT(5H INIT)                                                   EAM38310
 1008 FORMAT(5H STRT)                                                   EAM38320
 1009 FORMAT(7H TYPCON)                                                 EAM38330
 1010 FORMAT(14H ACTUATOR TEST)                                         EAM38340
 1011 FORMAT(12H MIRROR TEST)                                           EAM38350
 1012 FORMAT(7H MODFIN)                                                 EAM38360
 1016 FORMAT(5H STOP)                                                   EAM38370
 1017 FORMAT(3H JM)                                                     EAM38380
 1018 FORMAT(18H ACCEPT NEW VALUES)                                     EAM38390
 1019 FORMAT(12H NEW VALUE=?)                                           EAM38400
 1020 FORMAT(13H MODE TOO BIG)                                          EAM38410
 1021 FORMAT(16H DIAGNOSTIC MODE)                                       EAM38420
 1022 FORMAT(13H EDITING MODE)                                          EAM38430
 1023 FORMAT(18H PERFORMANCE INDEX)                                     EAM38440
 1024 FORMAT(6H I,J=?)                                                  EAM38450
 1025 FORMAT(12H RESTART JOB)                                           EAM38460
 1026 FORMAT(/,2HT=,F12.6,3HJM=,F12.6)                                  EAM38470
C                                                                       EAM38480
      GO TO (1,2,3,4,5,6,7,8,9),NENTRY                                  EAM38490
C                                                                       EAM38500
C     INITIALIZATION                                                    EAM38510
 1    RETURN                                                            EAM38520
C                                                                       EAM38530
C     OPERATION                                                         EAM38540
 2    CONTINUE                                                          EAM38550
C                                                                       EAM38560
C     SELECT EXPERIMENTAL MODE                                          EAM38570
 2280 WRITE(NTYPO,1006)                                                 EAM38580
      READ(NTYPI,1002) MODEQ                                            EAM38590
      WRITE(NTYPO,1002) MODEQ                                           EAM38600
      ICHNG=2                                                           EAM38610
C                                                                       EAM38620
      GO TO (2211,2212,2213,2214,2215,2216,2217,2218,2219,2220,2221,    EAM38630
     1 2222),MODEQ                                                      EAM38640
C                                                                       EAM38650
```

```
C     INITIALIZE MFCS
 2211 WRITE(NTYPO,1007)
      GO TO 2207
C
C     START MFCS
 2212 WRITE(NTYPO,1008)
      GO TO 2207
C
C     STOP MIRROR FIGURE CONTROL SYSTEM
 2213 WRITE(NTYPO,1016)
      GO TO 2207
C
C     TEST ACTUATORS
 2214 WRITE(NTYPO,1010)
      NFLGA=19
      RETURN
C
C     TEST MIRROR
 2215 WRITE(NTYPO,1011)
      NFLGA=20
      RETURN
C
C     DIAGNOSTIC MODE
 2216 WRITE(NTYPO,1021)
      GO TO 2990
C
C     MODIFY DATA TO NRUNC=NFLGC
 2217 READ(NTYPI,1002)NFLGC
      WRITE(NTYPO,1002)NFLGC
      NFLGA=22
      RETURN
C     RETURN TO SIMSYS(6) AND REENTER TYPCON(2)
C
C     UNUSED OPERATING MODE MODEQ=8
 2218 CONTINUE
      GO TO 2280
C
C     EVALUATE AND TYPE FIGURE PERFORMANCE INDEX
 2219 WRITE(NTYPO,1023)
      WRITE(NTYPO,1017)
C     RETURN TO SIGMA 5 TO CALCULATE THE PERFORMANCE INDEX
      NFLGA=12
      RETURN
C     RETURN TO MAINB(5) AND REENTER TYPCON(3)
C
C     TYPE VALUE OF THE PERFORMANCE INDEX
 3    WRITE(NTYPO,1005)QDUMVA(1)
      GO TO 2207
C
C     MODIFY DATA BUSS VALUE
 2220 WRITE(NTYPO,1022)
C     SET ICHNG=1
      ICHNG=1
      WRITE(NTYPO,1018)
      GO TO 2990
C
C     UNUSED OPERATING MODE MODEQ=11
```

```
 2221 GO TO 2207                                                        EAM39230
C                                                                       EAM39240
C     REQUEST MODE AGAIN IF MODE VALUE IS TOO LARGE                     EAM39250
 2222 WRITE(NTYPO,1020)                                                 EAM39260
      GO TO 2280                                                        EAM39270
C                                                                       EAM39280
C     IDENTIFY VARIABLE NAME                                            EAM39290
 2990 WRITE(NTYPO,1003)                                                 EAM39300
      READ(NTYPI,1000) NFLGC                                            EAM39310
      WRITE(NTYPO,1000) NFLGC                                           EAM39320
C     RETURN TO SIGMA 5 TO CATALOG AND CHECK VARIABLE NAME              EAM39330
      NFLGA=13                                                          EAM39340
      IGO=MODVQ(12)                                                     EAM39350
      GO TO (2995,2994),IGO                                             EAM39360
C*****EAM SOFTWARE TEST CODING******************************************EAM39370
 2995 CALL MAINB(3)                                                     EAM39380
 8    GO TO(5,6,4,2280),NFLGC                                           EAM39390
C*****EAM SOFTWARE TEST CODING******************************************EAM39400
 2994 RETURN                                                            EAM39410
C                                                                       EAM39420
C     OUTPUT ERROR MESSAGE IF NAME IS INCORRECT                         EAM39430
 4    WRITE(NTYPO,1001)                                                 EAM39440
      GO TO 2990                                                        EAM39450
C                                                                       EAM39460
C     IDENTIFY VARIABLE INDEX                                           EAM39470
 5    WRITE(NTYPO,1004)                                                 EAM39480
      READ(NTYPI,1002) NFLGD                                            EAM39490
      WRITE(NTYPO,1002) NFLGD                                           EAM39500
      GO TO 2330                                                        EAM39510
 6    WRITE(NTYPO,1024)                                                 EAM39520
      READ(NTYPI,1002) NFLGD,NFLGE                                      EAM39530
      WRITE(NTYPI,1002) NFLGD,NFLGE                                     EAM39540
C                                                                       EAM39550
C     ACCEPT NEW VALUE IF ICHNG=1                                       EAM39560
 2330 GO TO(2331,2340),ICHNG                                            EAM39570
 2331 WRITE(NTYPOQ,1019)                                                EAM39580
      READ(NTYPI,1005) QDUMVA(1)                                        EAM39590
C     RETURN TO SIGMA 5 T6 MODIFY AND/OR EXTRACT VALUE OF INTERROGATED  EAM39600
C     VARIABLE                                                          EAM39610
 2340 NFLGA=14                                                          EAM39620
      NFLGC=ICHNG                                                       EAM39630
      RETURN                                                            EAM39640
C     RETURN TO MIINB(4) AND REENTER TYPCON(7)                          EAM39650
C                                                                       EAM39660
C     DISPLAY VALUE OF INTERROGATED VARIABLE                            EAM39670
 7    WRITE(NTYPO,1005) QDUMVA(1)                                       EAM39680
      GO TO 2990                                                        EAM39690
C                                                                       EAM39700
C     NORMAL RETURN TO EAMCS                                            EAM39710
 2207 NFLGA=6                                                           EAM39720
      RETURN                                                            EAM39730
C                                                                       EAM39740
C     OUTPUT EXPERIMENT DATA ON REMOTE I/O DEVICE                       EAM39750
C                                                                       EAM39760
 9    WRITE(NTYPO,1026) QDUMVA(2),QDUMVA(1)                             EAM39770
      RETURN                                                            EAM39780
C     RETURN TO EAMCS                                                   EAM39790
C                                                                       EAM39800
      END                                                               EAM39810
```

APPENDIX B

EXPERIMENTAL ACTIVE MIRROR LIBRARY ROUTINE LISTINGS

B.1 EAM Library Routines

Considerable memory space can be saved by using subroutines to perform operations which are repeated a large number of times. Many small subroutines have been developed at MIT/DL to provide such common operations as matrix multiplication, data input and transfer, etc. In the EAM software package these subroutines appear as members of three libraries described in the following sections.

B.2 Miscellaneous Functions Package

This section presents listings of the subroutines which are used to perform a variety of program operations associated with the EAM but are not considered important enough for inclusion in Appendix A. This section describes the following programs.

```
SUBROUTINE EDITA(A,B,IB,NB,NENTRY)
SUBROUTINE IEDITA(IA,IB,IIB,NIB,NENTRY)
SUBROUTINE MARK(NENTRY,NSBA,NTYA,NSBB,NTYB)
SUBROUTINE NOIS(NENTRY)
SUBROUTINE REALT(TREAL)
SUBROUTINE REDUAM(NENTRY)
SUBROUTINE SATLIM(X,R,I)
FUNCTION   SGN(X)
FUNCTION   SNSWI(NENTRY)
SUBROUTINE TYPOUT(I,NENTRY)
```

```
      SUBROUTINE EDITA(A,B,IB,NB,NENTRY)
C
C     SUBROUTINE TO EDIT DATA
C
      DIMENSION A(1),B(1),IB(1)
C
      GO TO(1,2,3,4),NENTRY
C
C     READ NB AND IB
 1    CALL IRANDP(1,NB,IA,IA,IA,IA,IA,IA,4)
      CALL IMXRNP(IB,1,NB,4)
      RETURN
C
C     READ NEW VALUES AND CHANGE A
 2    CALL MXRNP(B,1,NB,4)
C
C     CHANGE A ONLY
 3    DO 2000 I=1,NB
      J=IB(I)
 2000 A(J)=B(I)
      RETURN
C
C     STORE OLD VALUES OF A IN B
 4    DO 2001 I=1,NB
      J=IB(I)
 2001 B(I)=A(J)
      RETURN
C
      END
      SUBROUTINE IEDITA(IA,IB,IIB,NIB,NENTRY)
C
C     SUBROUTINE TO EDIT DATA
C
      DIMENSION IA(1),IB(1),IIB(1)
C
      GO TO(1,2,3,4),NENTRY
C
C     READ NIB AND IIB
 1    CALL IRANDP(1,NIB,IK,IK,IK,IK,IK,IK,4)
      CALL IMXRNP(IIB,1,NB,4)
      RETURN
C
C     READ NEW VALUES AND CHANGE IA
 2    CALL IMXRNP(IB,1,NIB,4)
C
C     CHANGE IA ONLY
 3    DO 2000 I=1,NIB
      J=IIB(I)
 2000 IA(J)=IB(I)
      RETURN
C
C     STORE OLD VALUES OF IA IN IB
 4    DO 2001 I=1,NIB
      J=IIB(I)
 2001 IB(I)=IA(J)
      RETURN
C
      END
      SUBROUTINE MARK(NENTRY,NSBA,NTYA,NSBB,NTYB)
C
      DIMENSION NSAV(20),NTAV(20),NSBV(20),NTBV(20)
      COMMON/BLKSUP/ITRANS
C
 1000 FORMAT(17H TRANSITION ERROR,5I10)
C
      GO TO(1,2,2,4),NENTRY
C
 1    ITRANS=ITRANS+1
      IF(ITRANS-20)2003,2003,2004
 2004 PRINT 1000,ITRANS,NSBA,NTYA,NSBB,NTYB
      RETURN
C
 2003 NSAV(ITRANS)=NSBA
      NTAV(ITRANS)=NTYA
      NSBV(ITRANS)=NSBB
      NTBV(ITRANS)=NTYB
      RETURN
C
C     CALL TO EXTRACT DESTINATION
C
 2    IF(ITRANS)2000,2000,2001
 2000 PRINT 1000,ITRANS,NSBA,NTYA,NSBB,NTYB
      RETURN
C
 2001 GO TO(2002,2002,3,4),NENTRY
C
 2002 NSBA=NSAV(ITRANS)
      NTYA=NTAV(ITRANS)
      NSBB=NSBV(ITRANS)
      NTYB=NTBV(ITRANS)
      RETURN
C
C     CALL TO EXTRACT RETURN ADDRESS AND
C     DECREMENT TRANSITION COUNTER
C
 3    NSBB=NSBV(ITRANS)
      NTYB=NTBV(ITRANS)
      NSBA=NSAV(ITRANS)
      NTYA=NTAV(ITRANS)
      ITRANS=ITRANS-1
      RETURN
C
C     SET TRANSITION COUNTER TO ZERO
C
 4    ITRANS=0
      RETURN
C
      END
      SUBROUTINE NOIS(NENTRY)
C
C     SUBROUTINE TO GENERATE DISTURBANCES ON SYSTEM
C     DUMMY VERSION
C
      RETURN
C
      END
      SUBROUTINE REALT(TREAL)
C
C     SUBROUTINE TO INTERROGATE REAL TIME CLOCK
C
C     TREAL=REAL TIME
C
C
C     INSERT REAL TIME CLOCK INTERROGATION SOFTWARE HERE
C
C
C*****EAM SOFTWARE TEST CODING******************************************
      COMMON /BLKT/ T,DT,DTH,DTPLOT,DTNOIS,TPHI,TPRNT,TEND
      TREAL=T
C*****EAM SOFTWARE TEST CODING******************************************
      RETURN
C
      END
      SUBROUTINE REDUAM(NENTRY)
C
C     SUBROUTINE TO GENERATE AR AND ARR FROM A
C
C     SIGMA 5 TYPE B DIMENSION STATEMENTS START
      DIMENSION XFV(20),UFV(20),ASCALV(20),FSCALV(20),XFSV(20),
     1 YFSV(20),XFRV(20),DUMV(20),UFAV(20),DUMVA(20),GAINV(10),
     2 GAINM(1600),ASV(3)
      COMMON/BLKEAM/XFV,UFV,ASCALV,FSCALV,XFSV,YFSV,XFRV,DUMV,UFAV,
     1 DUMVA,GAINV,GAINM,ASV
C
      DIMENSION LACTV(20).
      COMMON/BKIEAM/LACTV,NCVEL,N,NR,NRA,MODE,MODOP,NSNSWT,NTYPI,
     1 NTYPO,NPUNCH,NMAG,NSENS,NWAIT,NPOS,NMINT,NMEAS,NFSENS,NTIMS
C
      DIMENSION AM(400),AIM(400)
      COMMON/BLKMFC/AM,AIM
C
      DIMENSION IAV(30),IBV(30),ICV(30),IDV(30),IEV(30),
     1 JCXV(10),JCPV(10),JICPV(10),CXV(10),CPV(10),ICPV(10),
     2 CXM(100),CPM(100),ICPM(100),NMCXV(10),NMCPV(10),NMICPV(10),
     3 MODV(20)
      COMMON/BLKIV/IAV,NIAV,IBV,NIBV,ICV,NICV,IDV,NIDV,IEV,NIEV,NX,NU,
     1 NCXV,NCPV,NICPV,JCXV, JCPV,JICPV,CXV,CPV,ICPV,CXM,CPM,ICPM,
     2 NMCXV,NMCPV,NMICPV,MODV
C
      DIMENSION AMM(400),WV(20),DUMBV(20),XFAV(20),XFDV(20)
      COMMON/BLKMDL/AMM,WV,DUMBV,XFAV,XFDV
C     SIGMA 5 TYPE B DIMENSION STATEMENTS END
C
 1000 FORMAT(/,13X,2HAR)
 1010 FORMAT(/,12X,3HARR)
 1020 FORMAT(7H REDUAM)
C
      GO TO(1,2),NENTRY
C
C     GENERATE AR BY REMOVING COLUMNS FROM A
 1    PRINT 1020
      K=0
      DO 2000 J=1,N
      IF(LACTV(J))2010,2000,2010
 2010 K=K+1
      DO 2020 I=1,N
      CALL LOC(I,J,IA,N,N,0)
      CALL LOC(I,K,IB,N,N,0)
 2020 AIM(IB)=AM(IA)
 2000 CONTINUE
C
C     COPY RESULT INTO AM
      CALL MCPY(AIM,AM,N,NR,0)
C
C     PRINT AR
      PRINT 1000
      CALL MXRNP(AM,N,NR,3)
      RETURN
C
C     GENERATE ARR FROM AR BY REMOVING ROWS FROM AR
 2    K=0
      DO 2100 I=1,N
      IF(LACTV(I))2110,2100,2110
 2110 K=K+1
      DO 2120 J=1,NR
      CALL LOC(I,J,IA,N,NR,0)
      CALL LOC(K,J,IB,NR,NR,0)
 2120 AIM(IB)=AM(IA)
 2100 CONTINUE
C
C     COPY RESULT INTO AM
      CALL MCPY(AIM,AM,NR,NR,0)
C
C     PRINT ARR
      PRINT 1010
      CALL MXRNP(AM,NR,NR,3)
      RETURN
C
      END
      SUBROUTINE SATLIM(X,R,I)
C
C     SUBROUTINE TO LIMIT THE RANGE OF A VARIABLE X TO -R<X<R
C
      IF(ABS(X)-R)2000,2000,2001
 2001 X=R*SGN(X)
 2000 RETURN
C
      END
      FUNCTION   SGN(X)
C
C     THE VALUE OF THE FUNCTION IS THE SIGN OF X
C
      IF(X)2000,2001,2001
 2000 SGN=-1.0
      GO TO 2002
 2001 SGN=+1.0
 2002 RETURN
C
      END
      FUNCTION   SNSWT(NENTRY)
C
C     DUMMY ROUTINE TO INTERROGATE SENSE SWITCHES
C
      SNSWT=0.0
      RETURN
C
      END
      SUBROUTINE TYPOUT(I,NENTRY)
C
C*****SUBROUTINE TO TYPE OUT MESSAGES
C
      GO TO(1,2,3,4,5),NENTRY
C
 1000 FORMAT(7H TYPOUT)
 1201 FORMAT(2HSS,I1)
 1202 FORMAT(12HNX TOO LARGE)
 1203 FORMAT(3HSS1)
C
 1    WRITE(NTYPE,1201) I
      RETURN
C
 2    WRITE(NTYPE,1202)
      RETURN
C
 3    WRITE(NTYPE,1203)
      RETURN
C
 4    PRINT 1000
      CALL IRANDP(1,NTYPE,IA,IA,IA,IA,IA,IA,4)
      RETURN
C
 5    CONTINUE
      RETURN
C
      END
```

B. 3 Mathematical Operations Package

This section presents listings of the subroutines which are used to perform mathematical operations on arrays.

```
FUNCTION    ELM(A,L,M,N)
SUBROUTINE  ELMA(NENTRY,A,I,J,V,N)
SUBROUTINE  GMADD(A,B,R,N,M)
SUBROUTINE  GMPRD(A,B,R,N,M,L)
SUBROUTINE  GMSUB(A,B,R,N,M)
SUBROUTINE  GMTRA(A,R,N,M)
SUBROUTINE  GTOSYM(X,XS,NX)
FUNCTION    IELM(IA,L,M,N)
SUBROUTINE  IMCPY(IA,IR,N,M,MS)
SUBROUTINE  LOC(I,J,IR,N,M,MS)
SUBROUTINE  MCPY(A,R,N,M,MS)
SUBROUTINE  MMADD(N,ALPHA,A,BETA,B,C)
SUBROUTINE  MPRD(A,B,R,N,M,MSA,MSB,L)
SUBROUTINE  MTRA(A,R,N,M,MS)
SUBROUTINE  SINV(N,AI,B,A,D)
SUBROUTINE  SYMTOG(XS,X,NX)
```

```
      FUNCTION ELM(A,L,M,N)
C
C     FUNCTION RETURNS THE VALUE OF THE L,M TH ELEMENT OF THE MATRIX
C     A WHICH HAS N ROWS AND AN ARBITRARY NUMBER OF COLUMNS
C     A WHICH HAS N ROWS AND AN ARBITRARY NUMBER OF COLUMNS
C     A IS STORED IN GENERAL FORM COLUMN BY COLUMN
C
      DIMENSION A(1)
C
      ELM=A(M*N-N+L)
      RETURN
C
      END
      SUBROUTINE ELMA(NENTRY,A,I,J,V,N)
C
C     SUBROUTINE TO WRITE INTO AND READ FROM MEMORY THE I,JTH ELEMENT
C     OF THE MATRIX A
C     A HAS N ROWS AND AN ARBITRARY NUMBER OF COLUMNS
C     A IS STORED IN GENERAL FORM COLUMN BY COLUMN
C
      DIMENSION A(1)
C
      GO TO(1,2),NENTRY
C
C     A(I,J)=V
 1    A(I+(J-1)*N)=V
      RETURN
C
C     V=A(I,J)
 2    V=A(I+(J-1)*N)
C
      RETURN
C
      END
      SUBROUTINE GMADD(A,B,R,N,M)
C
C     SUBROUTINE PERFORMS MATRIX ADDITION, R=A+B, WHERE A,B AND R ARE
C     N BY M MATRICES ARE GENERAL MATRICES STORED IN GENERAL FORM
C     COLUMN BY COLUMN
C
      DIMENSION A(1),B(1),R(1)
C
      NM=N*M
      DO 110 I=1,NM
  110 R(I)=A(I)+B(I)
      RETURN
C
      END
      SUBROUTINE GMPRD(A,B,R,N,M,L)
C
C     FORM THE PRODUCT R=A*B WHERE A IS A N*M MATRIX AND B IS A M*L
C     MATRIX
C     A,B AND R ARE STORED IN GENERAL MATRIX FORM COLUMN BY COLUMN
C
      DIMENSION A(1),B(1),R(1)
C
      IR=0
      IK=-M
      DO 10 K=1,L
      IK=IK+M
      DO 10 J=1,N
      IR=IR+1
      JI=J-N
      IB=IK
      R(IR)=0.0
      DO 10 I=1,M
      JI=JI+N
      IB=IB+1
   10 R(IR)=R(IR)+A(JI)*B(IB)
      RETURN
C
      END
      SUBROUTINE GMSUB(A,B,R,N,M)
C
C     SUBROUTINE PERFORMS MATRIX SUBTRACTION, R=A-B, WHERE A,B AND R ARE
C     N BY M MATRICES.
C     A,B AND R ARE STORED IN GENERAL MATRIX FORM COLUMN BY COLUMN
C
      DIMENSION A(1),B(1),R(1)
C
      NM=N*M
      DO 110 I=1,NM
 110  R(I)=A(I)-B(I)
      RETURN
C
      END
      SUBROUTINE GMTRA(A,R,N,M)
C
C     TRANSPOSE A GENERAL MATRIX
C
C     A - NAME OF MATRIX TO BE TRANSPOSED
C     R - NAME OF RESULTANT MATRIX
C     N - NUMBER OF ROWS OF A AND COLUMNS OF R
C     M - NUMBER OF COLUMNS OF A AND ROWS OF R
C
      DIMENSION A(1),R(1)
C
      IR=0
      DO 10 I=1,N
      IJ=I-N
      DO 10 J=1,M
      IJ=IJ+N
      IR=IR+1
   10 R(IR)=A(IJ)
      RETURN
C
      END
      SUBROUTINE GTOSYM(X,XS,NX)
C
C     PROGRAM CONVERTS A SQUARE NX BY NX MATRIX INTO A VECTOR OF LENGTH
C     NF*(NF+1)/2 AND WHOSE ELEMENTS CONSIST OF THE UPPER TRIANGLE OF
C     THE NX BY NX MATRIX, STORED IN COLUMNAR FORM.
C     THE MATRIX X MUST BE STORED IN GENERAL FORM COLUMN BY COLUMN
C
      DIMENSION X(1),XS(1)
C
      LL=0
      DO 10 J=1,NX
      DO 10 I=1,J
      LL=LL+1
      K=(J-1)*NX+I
 10   XS(LL)=X(K)
      RETURN
C
      END
      FUNCTION   IELM(IA,L,M,N)
C
C     FUNCTION RETURNS THE VALUE OF THE L,M TH ELEMENT OF THE MATRIX
C     IA WHICH  HAS N ROWS AND AN ARBITRARY NUMBER OF COLUMNS
C
      DIMENSION IA(1)
      IELM=IA(M*N-N+L)
      RETURN
C
      END
      SUBROUTINE IMCPY(IA,IR,N,M,MS)
C
C     MCPY COPIES ENTIRE  N BY M MATRIX IA INTO N BY M MATRIX IR
C         MS   - ONE DIGIT NUMBER FOR STORAGE MODE OF MATRIX IA (AND IR
C                 0 - GENERAL
C                 1 - SYMMETRIC
C                 2 - DIAGONAL
C
      DIMENSION IA(1),IR(1)
C
C     COMPUTE VECTOR LENGTH, IT
      CALL LOC(N,M,IT,N,M,MS)
C     COPY MATRIX
      DO 1 I=1,IT
 1    IR(I)=IA(I)
      RETURN
C
      END
      SUBROUTINE LOC(I,J,IR,N,M,MS)
C
C     SUBROUTINE TO GENERATE VECTOR SUBSCRIPT FOR AN ELEMENT IN A MATRIX
C     OF SPECIFIED STORAGE MODE.
C     MS =0  SUBSCRIPT IS COMPUTED FOR A MATRIX WITH N*M ELEMENTS
C            IN STORAGE (GENERAL MATRIX)
C     MS=1   SUBSCRIPT IS COMPUTED FOR A MATRIX WITH N*(N+1)/2 IN
C            STORAGE (UPPER TRIANGLE OF SUMMETRIC MATRIX).  IF
C            ELEMENT IS IN LOWER TRIANGULAR PORTION, SUBSCRIPT IS
C            CORRESPONDING ELEMENT IN UPPER TRIANGLE.
C     MS=2   SUBSCRIPT IS COMPUTED FOR A MATRIX WITH N ELEMENTS
C            IN STORAGE (DIAGONAL ELEMENTS OF DIAGONAL MATRIX).
C            IF ELEMENT IS NOT ON DIAGONAL (AND THEREFORE NOT IN
C            STORAGE), IR IS SET TO ZERO.
C
      IX=I
      JX=J
      IA=I-J
      IF(MS-1) 10,20,30
 10   IRX=N*(JX-1)+IX
      GO TO 36
 20   IF(IA)22,24,24
 22   IRX=IX+(JX*JX-JX)/2
      GO TO 36
 24   IRX=JX+(IX*IX-IX)/2
      GO TO 36
   30 IRX=0
      IF(IX-JX)36,32,36
   32 IRX=IX
 36   IR=IRX
      RETURN
C
      END
      SUBROUTINE MCPY(A,R,N,M,MS)
C
C     MCPY COPIES ENTIRE N BY M MATRIX A INTO N BY M MATRIX R
C           MS  - ONE DIGIT NUMBER FOR STORAGE MODE OF MATRIX A (AND R)
C                 0 - GENERAL
C                 1 - SYMMETRIC
C                 2 - DIAGONAL
C
      DIMENSION A(1),R(1)
C
C     COMPUTE VECTOR LENGTH, IT
      CALL LOC(N,M,IT,N,M,MS)
C     COPY MATRIX
      DO 1 I=1,IT
 1    R(I)=A(I)
      RETURN
C
      END
      SUBROUTINE MMADD(N,ALPHA,A,BETA,B,C)
C
C     SUBROUTINE TO FORM THE WEIGHTED SUM OF TWO ARRAYS
C     OF DIMENSION N
C     C=ALPHA*A+BETA*B
C
      DIMENSION A(1),B(1),C(1)
C
      DO 1 I=1,N
 1    C(I)=ALPHA*A(I)+BETA*B(I)
      RETURN
C
      END
      SUBROUTINE MPRD(A,B,R,N,M,MSA,MSB,L)
C
C     MPRD MULTIPLIES N BY M MATRIX A BY M BY L MATRIX B AND STORES THE
C     PRODUCT INTO N BY L MATRIX R
C           MSA - ONE DIGIT NUMBER FOR STORAGE MODE OF MATRIX A
C                 0 - GENERAL
C                 1 - SYMMETRIC
C                 2 - DIAGONAL
C           MSB - SAME AS MSA EXCEPT FOR MATRIX B
C
      DIMENSION A(1),B(1),R(1)
C
C     SPECIAL CASE FOR DIAGONAL BY DIAGONAL
      MS=MSA*10.+MSB
      IF(MS-22) 30,10,30
 10   DO 20 I=1,N
 20   R(I)=A(I)*B(I)
      RETURN
C
C     ALL OTHER CASES
 30   IR=1
      DO 90 K=1,L
      DO 90 J=1,N
      R(IR)=0
      DO 80 I=1,M
      IF(MS)40,60,40
 40   CALL LOC(J,I,IA,N,M,MSA)
      CALL LOC(I,K,IB,M,L,MSB)
      IF(IA)50,80,50
 50   IF(IB)70,80,70
 60   IA=N*(I-1)+J
      IB=M*(K-1)+I
 70   R(IR)=R(IR)+A(IA)*B(IB)
 80   CONTINUE
 90   IR=IR+1
      RETURN
C
      END
      SUBROUTINE MTRA(A,R,N,M,MS)
C
C     MTRA TRANSPOSES N BY M MATRIX A TO FORM M BY N MATRIX R
C           MS  - ONE DIGIT NUMBER FOR STORAGE MODE OF MATRIX A (AND R)
C                 0 - GENERAL
C                 1 - SYMMETRIC
C                 2 - DIAGONAL
C
      DIMENSION A(1),R(1)
C
C     IF MS IS 1 OR 2, COPY A
      IF(MS) 10,20,10
 10   CALL MCPY(A,R,N,N,MS)
      RETURN
C
C     TRANSPOSE GENERAL MATRIX
   20 IR=0
      DO 30 I=1,N
      IJ=I-N
      DO 30 J=1,M
      IJ=IJ+N
      IR=IR+1
 30   R(IR)=A(IJ)
      RETURN
C
      END
      SUBROUTINE SINV(N,AI,B,A,D)
C
C*****SUBROUTINE TO GENERATE THE INVERSE OF THE MATRIX AI
C     THE MATRICES AI AND B ARE STORED IN GENERAL FORM
C     INPUT MATRIX IS AI
C     OUTPUT INVERSE MATRIX IS B
C     N IS THE ORDER OF AI
C     D IS THE DETERMINANT OF AI
C
C           L - WORK VECTOR OF LENGTH N
C           M - WORK VECTOR OF LENGTH N
C
C           THE STANDARD GAUSS-JORDAN METHOD IS USED. THE DETERMINANT
C           IS ALSO CALCULATED. A DETERMINANT OF ZERO INDICATES THAT
C           THE MATRIX IS SINGULAR.
C*****WITH MODIFICATIONS TO INPUT MATRIX IN VECTOR FORMAT
C
C
C     DIMENSION AI(20,20),B(20,20),A(400),L(20),M(20)
      DIMENSION AI(1),B(1),A(1),L(20),M(20)
C
C        .................................................................
C
C        IF A DOUBLE PRECISION VERSION OF THIS ROUTINE IS DESIRED, THE
C        C IN COLUMN 1 SHOULD BE REMOVED FROM THE DOUBLE PRECISION
C        STATEMENT WHICH FOLLOWS.
C
C     DOUBLE PRECISION A,D,BIGA,HOLD
C
C        THE C MUST ALSO BE REMOVED FROM DOUBLE PRECISION STATEMENTS
C        APPEARING IN OTHER ROUTINES USED IN CONJUNCTION WITH THIS
C        ROUTINE.
C
C        THE DOUBLE PRECISION VERSION OF THIS SUBROUTINE MUST ALSO
C        CONTAIN DOUBLE PRECISION FORTRAN FUNCTIONS.  ABS IN STATEMENT
C        10 MUST BE CHANGED TO DABS.
C        STORAGE OF AI ELEMENT IN A
C
      KK=N*N
      DO 5 J=1,KK
 5    A(J)=AI(J)
C
C        .................................................................
C
C        SEARCH FOR LARGEST ELEMENT
C
      D=1.0
      NK=-N
      DO 80 K=1,N
      NK=NK+N
      L(K)=K
      M(K)=K
      KK=NK+K
      BIGA=A(KK)
      DO 20 J=K,N
      IZ=N*(J-1)
      DO 20 I=K,N
      IJ=IZ+I
 10   IF(ABS(BIGA)-ABS(A(IJ))) 15,20,20
 15   BIGA=A(IJ)
```

```
      L(K)=I
      M(K)=J
   20 CONTINUE
C
C        INTERCHANGE ROWS
C
      J=L(K)
      IF(J-K)35,35,25
   25 KI=K-N
      DO 30 I=1,N
      KI=KI+N
      HOLD=-A(KI)
      JI=KI-K+J
      A(KI)=A(JI)
   30 A(JI)=HOLD
C
C        INTERCHANGE COLUMNS
C
   35 I=M(K)
      IF(I-K)45,45,38
   38 JP=N*(I-1)
      DO 40 J=1,N
      JK=NK+J
      JI=JP+J
      HOLD=-A(JK)
      A(JK)=A(JI)
   40 A(JI)=HOLD
C
C        DIVIDE COLUMN BY MINUS PIVOT (VALUE OF PIVOT ELEMENT IS
C        CONTAINED IN BIGA)
C
   45 IF(BIGA) 48,46,48
   46 D=0.0
      GO TO 150
   48 DO 55 I=1,N
      IF(I-K)50,55,50
   50 IK=NK+I
      A(IK)=A(IK)/(-BIGA)
   55 CONTINUE
C
C        REDUCE MATRIX
C
      DO 65 I=1,N
      IK=NK+I
      HOLD=A(IK)
      IJ=I-N
      DO 65 J=1,N
      IJ=IJ+N
      IF(I-K)60,65,60
   60 IF(J-K)62,65,62
   62 KJ=IJ-I+K
      A(IJ)=HOLD*A(KJ)+A(IJ)
   65 CONTINUE
C
C        DIVIDE ROW BY PIVOT
C
      KJ=K-N
      DO 75 J=1,N
      KJ=KJ+N
      IF(J-K)70,75,70
```

```
 70   A(KJ)=A(KJ)/BIGA
 75   CONTINUE
C
C        PRODUCT OF PIVOTS
C
      D=D*BIGA
C
C        REPLACE PIVOT BY RECIPROCAL
C
      A(KK)=1.0/BIGA
 80   CONTINUE
C
C        FINAL ROW AND COLUMN INTERCHANGE
C
      K=N
 100  K=(K-1)
      IF(K) 150,150,105
 105  I=L(K)
      IF(I-K)120,120,108
 108  JQ=N*(K-1)
      JR=N*(I-1)
      DO 110 J=1,N
      JK=JQ+J
      HOLD=A(JK)
      JI=JR+J
      A(JK)=-A(JI)
 110  A(JI)=HOLD
 120  J=M(K)
      IF(J-K) 100,100,125
 125  KI=K-N
      DO 130 I=1,N
      KI=KI+N
      HOLD=A(KI)
      JI=KI-K+J
      A(KI)=-A(JI)
 130  A(JI)=HOLD
      GO TO 100
 150  LL=0
C     DO 151 J=1,N
      KK=N*N
      DO 151 J=1,KK
 151  B(J)=A(J)
      RETURN
C
      END
      SUBROUTINE SYMTOG(XS,X,NX)
C
C     PROGRAM CONVERTS A SYM. MATRIX VECTOR (IN SUPPRESSED SYM. STORAGE)
C     WHOSE LENGTH IS NX*(NX+1)/2, INTO A GENERAL MATRIX VECTOR WHOSE
C     LENGTH IS NX*NX.
C
      DIMENSION X(1),XS(1)
C
      LL=0
      DO 10 J=1,NX
      DO 10 I=1,J
      LL=LL+1
      K=(J-1)*NX+I
      M=(I-1)*NX+J
      X(M)=XS(LL)
 10   X(K)=XS(LL)
      RETURN
C
      END
```

B. 4 Input-Output Operations Package

This section presents listings and usage descriptions of subroutines which are used to perform input-output data operations.

```
SUBROUTINE IMXRNP(M,NA,NB,NENTRY)
SUBROUTINE IRANDP(ND,IA,IB,IC,ID,IE,IF,IG,NENTRY)
SUBROUTINE MXRNP(VA,NA,NB,NENTRY)
SUBROUTINE NAMRNP(M,NA,NB.NENTRY)
SUBROUTINE RANDP(NENTRY)
SUBROUTINE RANDPD(ND,DA,DB,DC,DD,DE,DF,DG.NENTRY)
```

```
      SUBROUTINE IMXRNP(M,NA,NB,NENTRY)
C
C     SUBROUTINE READS,PRINTS AND STORES INTEGER NA*NB MATRIX
C     MATRIX IS STORED IN GENERAL FORM COLUMN BY COLUMN
C
      DIMENSION M(1)
C
 1000 FORMAT(7I10)
 1002 FORMAT(7I15)
C
C     READ IN NA BY NB MATRIX ROW-WISE AND STORE INTO 1 DIMENSION
C     VECTOR COLUMN-WISE.
      GO TO(1,1,2,4,2),NENTRY
C
 1    J=NA*NB-NA+1
      DO 15 I=1,NA
      READ 1000, (M(K),K=I,J,NA)
 15   J=J+1
C
      GO TO(2,3,3,2),NENTRY
C
C     PRINT NA BY NB MATRIX ROW-WISE
 2    CONTINUE
      JJ=NA*NB-NA+1
      DO 11 II=1,NA
      IF(NENTRY-5)12,10,12
 10   PUNCH 1000,(M(L),L=II,JJ,NA)
      GO TO 11
 12   PRINT 1002, (M(L),L=II,JJ,NA)
 11   JJ=JJ+1
C
 3    RETURN
C
C     READ AND PRINT HEADING CARD BEFORE READING AND PRINTING MATRIX
 4    CALL RANDP(4)
      GO TO 1
C
      END
      SUBROUTINE IRANDP(ND,IA,IB,IC,ID,IE,IF,IG,NENTRY)
C
C     SUBROUTINE TO READ AND PRINT INTEGER DATA
C
      DIMENSION IV(7)
C
 1000 FORMAT(7I10)
 1010 FORMAT(7I15)
C
      GO TO(1,1,2,4),NENTRY
 1    READ 1000,IA,IB,IC,ID,IE,IF,IG
      GO TO(2,3,3,2),NENTRY
 2    IV(1)=IA
      IV(2)=IB
      IV(3)=IC
      IV(4)=ID
      IV(5)=IE
      IV(6)=IF
      IV(7)=IG
      PRINT 1010,(IV(I),I=1,ND)
 3    RETURN
C
 4    CALL RANDP(4)
      GO TO 1
C
      END
      SUBROUTINE MXRNP(VA,NA,NB,NENTRY)
C
C     SUBROUTINE READS AND/OR PRINTS THE NA*NB MATRIX VA WHICH IS STORED
C     GENERAL FORM COLUMN BY COLUMN
C
      DIMENSION VA(1)
C
 1000 FORMAT(7E10.0)
 1002 FORMAT(7F15.6)
 1003 FORMAT(7F10.4)
C
      GO TO(1,1,2,4,2),NENTRY
C
C     READ IN NA BY NB MATRIX ROW-WISE AND STORE INTO 1 DIMENSION
C     VECTOR COLUMN-WISE.
 1    J=NA*NB-NA+1
      DO 15 I=1,NA
      READ 1000, (VA(K),K=I,J,NA)
 15   J=J+1
      GO TO(2,3,3,2),NENTRY
C
 2    CONTINUE
C     PRINT NA BY NB MATRIX ROW-WISE
      JJ=NA*NB-NA+1
      DO 11 II=1,NA
      IF(NENTRY-5)12,10,12
 10   PUNCH 1003,(VA(L),L=II,JJ,NA)
      GO TO 11
 12   PRINT 1002, (VA(L),L=II,JJ,NA)
 11   JJ=JJ+1
      RETURN
C
 3    RETURN
C
C     READ AND PRINT HEADING CARD BEFORE READING AND PRINTING MATRIX
 4    CALL RANDP(4)
      GO TO 1
C
      END
      SUBROUTINE NAMRNP(M,NA,NB,NENTRY)
C
C     SUBROUTINE READS,PRINTS AND STORES INTEGER NA*NB MATRIX
C     OF FOUR CHARACTER NAMES
C     MATRIX IS STORED IN GENERAL FORM COLUMN BY COLUMN
C
      DIMENSION M(1)
C
 1000 FORMAT(1X,A4,1X,A4,1X,A4,1X,A4,1X,A4,1X,A4,1X,A4,1X,A4,1X,A4,
     1 1X,A4,1X,A4,1X,A4,1X,A4,1X,A4)
 1002 FORMAT(11X,A4,11X,A4,11X,A4,11X,A4,11X,A4,11X,A4,11X,A4)
C
      GO TO(1,1,2,4),NENTRY
C
C     READ IN NA BY NB MATRIX ROW-WISE AND STORE INTO 1 DIMENSION
C     VECTOR COLUMN-WISE.
 1    J=NA*NB-NA+1
      DO 15 I=1,NA
      READ 1000, (M(K),K=I,J,NA)
 15   J=J+1
      GO TO(2,3,3,2),NENTRY
C
C     PRINT NA BY NB MATRIX ROW-WISE
 2    CONTINUE
      JJ=NA*NB-NA+1
      DO 11 II=1,NA
      PRINT 1002,(M(L),L=II,JJ,NA)
 11   JJ=JJ+1
C
 3    RETURN
C
C     READ IN HEADING CARD BEFORE READING AND PRINTING M
 4    CALL RANDP(4)
      GO TO 1
C
      END
      SUBROUTINE RANDP(NENTRY)
C
C     SUBROUTINE TO READ AND PRINT HEADING CARDS
C
      DIMENSION FNAME(8)
      DOUBLE PRECISION FNAME
C
 1000 FORMAT(8A8)
 1001 FORMAT(1H1)
 1010 FORMAT(2X,A8,2X,A8,2X,A8,2X,A8,2X,A8,2X,A8,2X,A8)
 1020 FORMAT(7X,A8,7X,A8,7X,A8,7X,A8,7X,A8,7X,A8,7X,A8)
C
      GO TO(1,2,3,4),NENTRY
C
 1    PRINT 1001
 2    READ 1000,(FNAME(I),I=1,8)
      PRINT 1000,(FNAME(I),I=1,8)
      RETURN
C
 3    PRINT 1001
 4    READ 1010,(FNAME(I),I=1,7)
      PRINT 1020,(FNAME(I),I=1,7)
      RETURN
C
      END
      SUBROUTINE RANDPD(ND,DA,DB,DC,DD,DE,DF,DG,NENTRY)
C
C     SUBROUTINE TO READ AND PRINT FLOATING POINT DATA
C
      DIMENSION DV(7)
C
 1000 FORMAT(7E10.0)
 1010 FORMAT(7F15.6)
C
      GO TO(1,1,2,4),NENTRY
C
 1    READ 1000,DA,DB,DC,DD,DE,DF,DG
      GO TO(2,3,3,2),NENTRY
 2    DV(1)=DA
      DV(2)=DB
      DV(3)=DC
      DV(4)=DD
      DV(5)=DE
      DV(6)=DF
      DV(7)=DG
      PRINT 1010,(DV(I),I=1,ND)
 3    RETURN
C
 4    CALL RANDP(4)
      GO TO 1
C
      END
```

TABLE OF REFERENCES

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TABLE OF SYMBOLS

Variable	Definition	Software *** Notation
A	deformation-force or position-position matrix	AM
A_m	actual deformation-force or position-position matrix of the mirror	AMM
A_{mr}	reduced version of A_m	*
A_r	reduced A matrix	*
A_{rr}	doubly reduced A matrix	*
a_s	ambiguity sensor outputs	ASV
g_{tilt}	tilt control system gain	GTILT
J_a	actual rms figure error	*
J_{fs}	figure sensor performance index	*
J_m	measured rms figure error	PINDEX
K	feedback gain matrix	GAINM
K_a	actuator error gain	GA
K_g	generalized linear control system gain matrix	GAINM
K_ℓ	simplified linear control system gain matrix	GAINM
$k_{\ell d}$	lead screw gain	
K_o	linear optimal control system gain matrix	GAINM
k_{sa}	integral of actuator output gain	GB
m_c	desired figure actuator outputs	UFV

* Stored temporarily.

** The diagonal elements of the diagonal matrix B are stored in the array WGTV.

*** Corresponding sigma 2 variable names may be generated by prefixing Q to floating point variable names or suffixing Q to fixed point variable names.

Variable	Definition	Software Notation
$\hat{m}_c$	scaled value of m_c	QUFV
m_g	scalar gains relating actuator commands	ASCALV
m_o	measured figure actuator outputs	UFAV
m_{max}	maximum actuator command magnitude	UFMAX
m_m	measured actuator output	UFAV
n	number of measurement positions	N
N	motor gear ratio	
n_{ma}	number of actuator slope measurements to be performed and averaged	NMEAS*
n_{mf}	number of A_r matrices to be measured experimentally and averaged	NMEAS*
n_{meas}	number of measurement samples at each measurement location	NMEAS*
n_{mint}	number of cycles between measurements	NMINT
n_{pos}	number of cycles alloted for figure sensor transients to decay	NPOS
n_r	number of actuators	NR
n_{tilt}	number of measurement position increments during tilt alignment	NTILT
n_{tims}	total number of cycles executed when EAMCS is called	NTIMS
n_{wait}	number of cycles during which the actuators are operative	NWAIT
n_ω	number of control cycles velocity pulse is applied $t_\omega = n_\omega \Delta t$	NCVEL
t	time	T
t_a	actuator time constants	TACTV

* Ambiguity does not occur in the software because NMEAS is not in common.

Variable	Definition	Software Notation
t_f	figure sensor filter time constant	FSTFLT
t_s	control computation cycle time	TSENS
t_ω	velocity command pulse width	TCVEL
W	performance index weighting factors	WGTV
x	x figure error position coordinate	XFSV
x_d	initial figure disturbance with zero actuator input	XFDV
x_f	actual figure error	XF
x_{fr}	reduced measured figure error vector	XFRV
x_{fp}	processed figure error data	XFV
x_{fm}	measured figure error	XF
x_{sf}	vector of the sums of the figure measurements at the measurement locations	QDUMVB
x_{ssf}	vector of the sums of the squares of the figure measurements at the measurement locations	QDUMVC
y	y figure error position coordinate	YFSV

GREEK SYMBOLS

α_m	slew control system command	UFV
β_{ab}	ambiguity correction value	AMBIG
β_{as}	mirror model matrix scale factor	ASCALE
β_f	figure sensor phase detector filter output	FSFLTO
β_{ft}	threshold level on the rms figure error	SIGLIM
β_g	scalar gain factor	GAIN(1)

Variable	Definition	Software Notation
β_k	control law gain factor	GAIN(1)
$\beta_{\ell f}$	stored value of β_{mf}	
β_{mf}	mean values of the figure measurements	XFMN
β_{mrf}	rms values of the figure measurements	XFSIG
β_{ms}	matrix inversion scale factor	AIMSCL
β_{nf}	noise input to the figure sensor phase detector	FSNOIS
β_p	figure sensor phase detector output	FSPDO
β_{sd}	second-order ambiguity sensor output coefficient	BSDP
β_{sm}	maximum ambiguity sensor output	BSMP
β_{sw}	computer switching boundary	XFSW
β_t	threshold value for rms measurement error	SIGLIM
β_{ts}	threshold value and ambiguity factor computation	BTS
β_{xa}	actual figure sensor error	UFV
β_{xf}	figure error input	XF
β_z	interpolation factor	SLPMN
β_ω	amplitude of the position control system velocity drive pulse	CVEL
γ_a	actuator input transition matrices	AGAMV
γ_f	figure sensor filter input transition matrix	FSGAM
Δt	real time control system cycle time	TSENS
δ_{aa}	actuator perturbation for actuator test	DACT *
δ_{af}	actuator perturbation for mirror model generation	DACT *

* Not in common.

Variable	Definition	Software Notation
λ	figure sensor laser operating wavelength	
σ_f	rms figure error noise level	FSNSIG
ν_f	figure sensor noise	FSNOIS
ϕ_a	actuator state transition matrices	APHIV
ϕ_f	figure sensor filter transition matrix	FSPHI

Software** Notation	Definition	Variable
AGAMV	actuator input transition matrices	γ_a
AIMSCL	matrix inversion scale factor	β_{ms}
AM	deformation-force or position-position matrix	A
AMBIG	ambiguity correction value	β_{ab}
AMM	actual deformation-force or position-position matrix of the mirror	A_m
APHIV	actuator state transition matrices	ϕ_a
ASCALE	mirror model matrix scale factor	β_{as}
ASCALV	scalar gains relating actuator commands	m_g
ASV	vector of ambiguity sensor outputs	a_s
BSDP	second-order ambiguity sensor output coefficient	β_{sd}
BSMP	maximum ambiguity sensor output	β_{sm}
BTS	threshold value and ambiguity factor computation	β_{ts}
CPM	stored PARV modifications	
UFV	amplitude of the position velocity drive pulse	β_ω
CXM	stored XV modifications	
DACT*	actuator perturbation for actuator test	δ_{aa}
DACT*	actuator perturbation for mirror model generator	δ_{af}

* Ambiguity does not occur in the software because DACT is not in common.

** Variable names containing Q may be referenced by deleting the Q and referencing the resulting name (i.e., NQ → N)

Software Notation	Definition	Variable
DT	real time control system cycle time	Δt
DTE	time round off correction factor	
DTNOIS	stochastic noise generation interval	
DTPLOT	plot data storage interval	
FSCALE	figure sensor measurement scale factor	
FSFLTO	figure sensor phase detector filter output	β_f
FSGAM	figure sensor filter input transition matrix	γ_f
FSPHI	figure sensor filter state transition matrix	φ_f
FSPDO	figure sensor phase detector output	β_p
FSNOIS	noise input to the figure sensor phase detector	β_{nf}
FSNSIG	rms figure error noise level	σ_f
FSTFLT	figure sensor filter time constant	t_f
GA	actuator error gain	K_a
GAINM	feedback gain matrix	K
GAINM	simplified linear control system gain matrix	K_ℓ
GAINM	linear optimal control system gain matrix	K_o
GAINM	generalized linear control system gain matrix	K_g
GAIN(1)	scalar gain factor	β_g
GB	integral of actuator error gain	k_{sa}
GTILT	tilt control system gain	g_{tilt}
ICPM	stored integer parameter modifications	

Software Notation	Definition	Variable
IMODV	plot scaling control vector	
IPLOTV	plotted elements of the data transfer vector XV	
IRAND	initial starting value for random number generator	
ISPARV	input data storage	
JCPV	modified elements of PARV	
JCXV	modified elements of XV	
JICPV	modified elements of IPARV	
LACTV	actuator position assignment vector	
LREFAV	segmented mirror actuator assignments	
MODOP	control system type identifier	
MODV	vector of operating modes	
MSEQV	figure sensor scan sequence	
N	number of figure measurement points	n
NCPV	number of modified parameter values	
NCTILT	number tilt control system control system operating cycles	
NCVEL	number of control cycles velocity pulse is applied $t_\omega = n_\omega \Delta t$	n_ω
NCXV	number of modified initial conditions	
NFLGA-NFLGD	transfer identification variables	
NHC	number of step size halvings	
NHM	maximum number of step size halvings	
NIC	number of successful iterations	

Software Notation	Definition	Variable
NICPV	number of integer parameters to be changed	
NIM	maximum number of iterations	
NMAG	magnetic storage device assignment	
NMCPV	names of modified parameters	
NMCXV	names of modified initial conditions	
NMEAS*	number of measurement samples at each measurement location	n_{meas}
NMEAS*	number of actuator slope measurements to be performed and averaged	n_{ma}
NMEAS*	number of A_r matrices to be measured experimentally and averaged	n_{mf}
NMICPV	names of modified integer parameters	
NMINT	number of cycles between measurements	n_{mint}
NPLOTV	number of plotted variables	
NPOS	number of cycles alloted for figure sensor transients to decay	n_{pos}
NPUNCH	device assignment for punched output	
NR	number of figure actuators	n_r
NRUN	run identification number	
NRUNC	number of completed runs	
NRUNM	maximum number of runs	
NSNSWT	sense switch assignment	

* Ambiguity does not occur in the software because NMEAS is not in common.

Software Notation	Definition	Variable
NTILT	number of measurement position increments during tilt alignment	n_{tilt}
NTIMS	total number of cycles executed when EAMCS is called	n_{tims}
NTYO	number of control computations between monitor data output	
NTYPE	operator display assignment for manual simulation control	
NTYPI	remote control input device assignment	
NTYPO	remote control output device assignment	
NWAIT	number of cycles during which the actuators are operative	n_{wait}
PINDEX	measured rms figure error	J_m
PLOTV	plotted data vector	
PSCALE	measurement position scale factor	
QDUMVB	vector of the sums of the figure measurements at the measurement locations	x_{sf}
QDUMVC	vector of the sums of the squares of the figure measurements at the measurement locations	x_{ssf}
SCALV	plotted data scales	
SIGLIM	threshold level on the rms figure error	β_{ft}
SLPMN	interpolation factor	β_z
SMXV	segmented mirror actuator x coordinate values	
SMYV	segmented mirror actuator y coordinate values	

Software Notation	Definition	Variable
SPARV	input data storage	
SXV	input data storage	
T	time	t
TACTV	actuator time constants	t_a
TEND	simulation run termination time	
TPRNT	interval between simulation output print	
TSENS	figure control computation cycle time	t_s
TVEL	velocity command pulse width	t_ω
UFAV	measured figure actuator outputs	m_m
UFMAX	maximum control command magnitude	m_{max}
UFV	desired figure actuator outputs	m_c
WGTV	performance index weighting factors	w
XF	actual figure error	x_f
XFDV	initial figure error ($m_m = 0$)	x_d
XFV	measured figure error	x_{fm}
XFRV	reduced measured figure error vector	x_{fr}
XFMN	mean values of the figure measurements	β_{mf}
XFSIG	rms values of the figure measurements	β_{mrf}
XFSV	x figure error position coordinate	x
XFSW	nearest phase switching boundary	β_{sw}
XFV	actual figure sensor error	β_{xa}
XFV	processed figure error data	x_{fp}
XV	data transfer vector	
YFSV	y figure error position coordinate	y